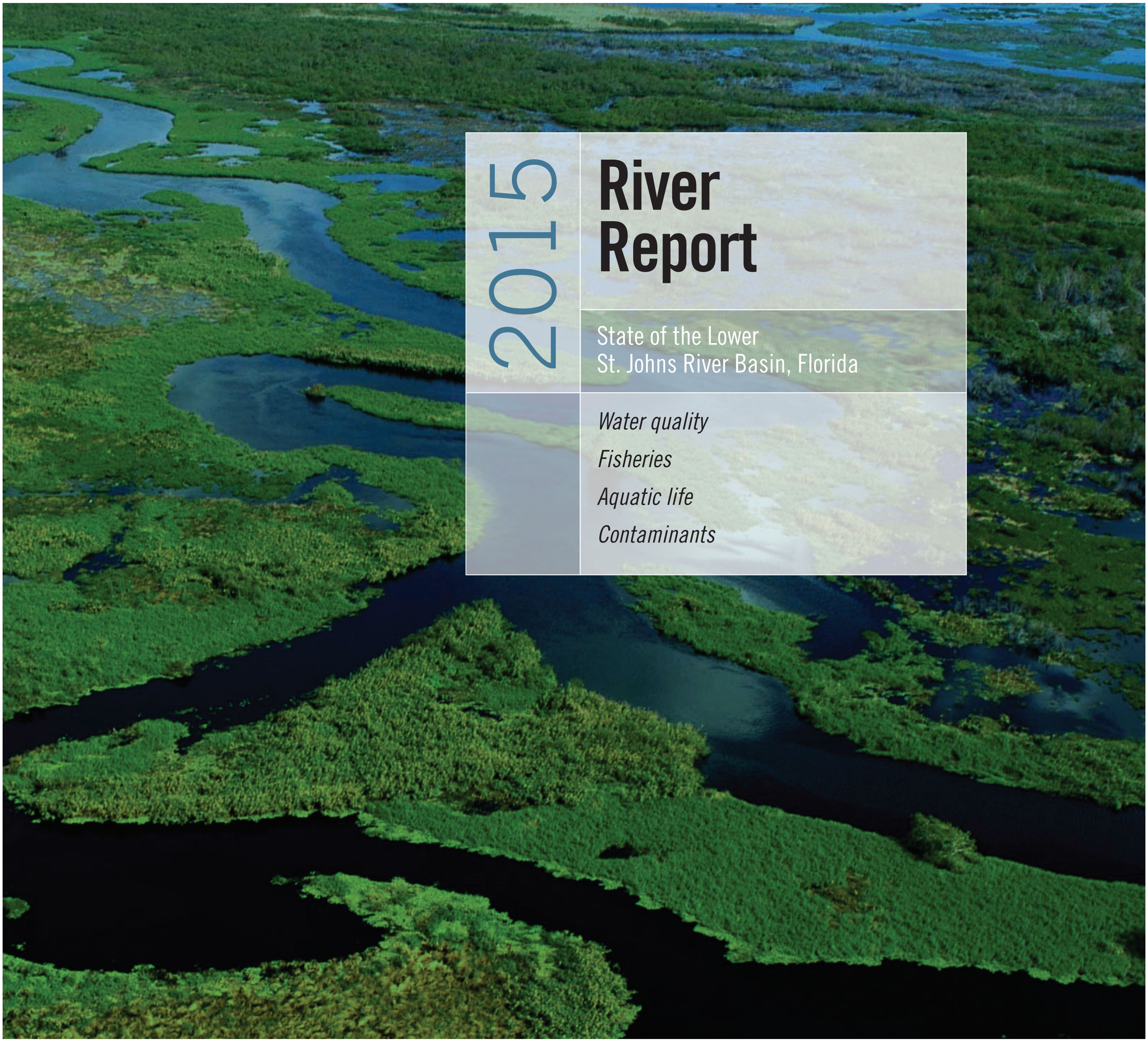

2015

River Report

State of the Lower St. Johns River Basin, Florida

Water quality

Fisheries

Aquatic life

Contaminants

Prepared for:

Environmental Protection Board, City of Jacksonville, Florida

St. James Building, 117 West Duval Street Jacksonville, Florida 32202

By:

University of North Florida, 1 UNF Drive, Jacksonville, Florida 32224

Jacksonville University, 2800 University Blvd N., Jacksonville, Florida 32211

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Preface

The State of the River Report is the result of a collaborative effort of a team of academic researchers from Jacksonville University, University of North Florida, Jacksonville, FL, and Valdosta State University, Valdosta, GA. The report was supported by the Environmental Protection Board of the City of Jacksonville and the River Branch Foundation. The purpose of the project is to review various previously collected data and literature about the river and to place it into a format that is informative and readable to the general public. The report consists of three parts---the brochure, the full report, and an appendix. The short brochure provides a brief summary of the status and trends of each item or indicator (i.e. water quality, fisheries, etc.) that was evaluated for the river. The full report and appendix were produced to provide more to those interested. In the development of these documents, many different sources of data were examined, including data from the Florida Department of Environmental Protection, St. Johns River Water Management District, Fish and Wildlife Commission, City of Jacksonville, individual researchers, and others. The researchers reviewed data addressing many different aspects of the Lower St. Johns River. The most statistically rigorous and stringent research available was used to assemble the report. When a draft of all documents was produced, an extensive review process was undertaken to ensure accuracy, balance, and clarity. We are extremely grateful to the following scientists and interested parties who provided invaluable assistance in improving our document.

Vince Seibold
Betsy Deuerling City of Jacksonville
John Hendrickson, SJRWMD
John Higman, SJRWMD
Dean Dobberfuhl, SJRWMD
Teresa Monson, SJRWMD
Al Canepa, SJRWMD
Derek Busby, SJRWMD
Russ Brodie, FWRI
Tony DiGirolamo, FWRI
Justin Solomon, FWRI
Lee Banks, FL DEP
Patrick O'Connor, FL DEP
Melissa Long, FL DEP
Lisa Rinaman, St. Johns River Riverkeeper
Paul Steinbrecher, JEA
Tiffany Busby, Wildwood Consulting
Marcy Policastro, Wildwood Consulting
Mike McManus, The Nature Conservancy
Richard Bryant, National Park Service
Mark Middlebrook, St. Johns River Alliance
Maria Mark, Timucuan Trail Parks Foundation
Stephan Nix, University of North Florida
Kelly Smith, University of North Florida
Dale Casamatta, University of North Florida
Robert Richardson, University of North Florida
Maia McGuire, University of Florida Sea Grant
A. Quinton White, Jacksonville University
Charles Jacoby, SJRWMD
Ted Lange, FWRI
Douglas Adams, FWRI
Donald Axelrad, FL DEP
Barbara Donner, FL DEP
Kendra Goff, FL DOH
Jan Landsberg, FWRI

Robert Storm Burks, SJRWMD
Matthew Waters, Valdosta State University
Christopher Swanson, FWRI
Gary Weise

We have appreciated the opportunity to work with the environmental community to educate the public about the unique problems of the Lower St. Johns River, and the efforts that are under way to restore our river to a healthy ecosystem.

We would also like to thank the following undergraduate students for their contributions toward the development of this report:

Laura Elston, Jacksonville University
Bobbi Estabrook, Jacksonville University
Jessica Fernquist, Jacksonville University
Jessica Goodman, Jacksonville University
Julia Goodman, Jacksonville University
Julie Hammon, Jacksonville University
Leon Huderson, III, Jacksonville University
Jingu Gene Kang, Jacksonville University
Ryan Keith, Jacksonville University
Rebecca Lucas, Jacksonville University
Nicole Martin, Jacksonville University
Andrea Pertoso, University of North Florida
David Roueche, Jacksonville University
Logan Wood, Jacksonville University
Jenna Manis, Jacksonville University
Samuel Dixie, Jacksonville University
Katie Anagnostou, University of North Florida
Anthony Flock, Jacksonville University
Sara Debellis, Jacksonville University
Alexis Crouch, Jacksonville University
Keenan Carpenter, Jacksonville University
Krystal Dannenhoffer, Jacksonville University
Emma Fowler, Jacksonville University

Sincerely,

Lucy Sonnenberg, Principal Investigator, JU
Gerry Pinto, JU
Nisse Goldberg, JU
Anthony Oulette, JU

Radha Pyati, Principal Investigator, UNF
Gretchen Bielmyer-Fraser, Valdosta State University
Stuart Chalk, UNF
Peter Bacopoulos, UNF
Brian Zoellner, UNF

Executive Summary

The Eighth State of the River Report is a summary and analysis of the health of the Lower St. Johns River Basin (LSJRB). The Report addresses four main areas of river health: water quality; fisheries; aquatic life; and contaminants. Section 1 provides an overview of the Report and the basin, and it describes the basin's landscape, human occupancy, and environmental management spanning the 1800s to 2014.

Section 2 describes water quality in terms of dissolved oxygen, nutrients, algal blooms, turbidity, fecal coliform, tributaries, and salinity. Dissolved oxygen concentrations in the river's mainstem show a steady trend of meeting acceptable limits in terms of the annual median value, but during the course of one year, the minimum DO values are low enough to cause concern for aquatic life. Average annual total nitrogen concentrations are slowly declining throughout the river since 1997. Total phosphorus levels are declining only in the marine/estuarine section, but not in the freshwater section. Chlorophyll a, an indicator measurement for algal blooms, shows no signs of improving in the mainstem. Turbidity levels have remained stable over the past several years. High levels of fecal coliform bacteria are a very important problem in the tributaries, but levels have been falling in many impaired tributaries and conditions are improving. Trends in fecal coliform have indicated improvement in the tributaries. Salinity is discussed in terms of modeling, longitudinal variation, depth dependence, and biological impacts. Effects of salinity on biological systems are complex but rely strongly on impacts to submerged aquatic vegetation.

Section 3 addresses the state of the river's finfish and invertebrate fisheries. Blue crabs comprise 73% of the commercial fishery catch in the region, followed by striped mullet at 19%. The incidence of gross external abnormalities in finfish was less than one percent in 2001 to 2010, and mercury levels in several species suggest limited consumption of only 1-8 meals per month. Most finfish and invertebrate species are not in danger of overfishing, with the exception of channel and white catfish and Penaeid shrimp, which both have the potential to be overfished in the near future. Stone crabs are currently at their maximum level of harvesting.

Section 4 examines the condition of aquatic life, encompassing plants, animals, and wetlands. Submerged aquatic vegetation (SAV), including commonly observed species like tape grass and widgeon grass, has exhibited decreased grass bed cover correlated with increased salinity. Monitoring of SAV was suspended in 2012. Wetlands perform vital functions in the Northeast Florida ecosystem, including removal of nitrogen and phosphorus, and their value from an ecosystem services perspective is high. Diversity and abundance of macroinvertebrates, such as crabs, clams, snails, worms, insects, and shrimp, vary widely but in general are dominated by the more pollution-tolerant species. Threatened and endangered species, namely the Florida manatee, wood stork, shortnose sturgeon, piping plover, Florida scrub jay, and eastern indigo snake, continue to be vulnerable due to habitat loss, increased boating traffic, drought, and threats to SAV. Budget cuts to monitoring programs limit understanding of these populations. A total of 74 non-native aquatic species are documented in the LSJRB; this is the first year in several years that the number of species has not increased.

Section 5 discusses the importance of contaminants in the LSJRB. The EPA Toxics Release Inventory in 2013 showed that 91% of all chemicals released by regional entities are discharged into the atmosphere and consist largely of acid gases emitted by electric utilities. The portion of chemicals released directly into the waters of the LSJRB is dominated by nitrates and manganese from the U.S. Department of Defense and the paper industry. In general, emissions of chemicals to the atmosphere declined by over 70% between 2000 and 2013, due largely to reductions in acid emissions by electric utilities, but discharges to surface waters have increased by 34%. Mercury, the subject of a new statewide reduction effort, is emitted to both air and surface waters in the LSJRB in fairly steady quantities. Concentrations of metals in the water column have been at or below the water quality criterion for the last three years, except for copper and silver; however, numerous tributaries exhibit elevated metal concentrations. The sediment contaminant classes evaluated include polycyclic aromatic hydrocarbons (PAHs), metals, polychlorinated biphenyls (PCBs), and pesticides that contain chlorine. Currently, metals and PAHs cause the most toxicity to sediment-dwelling organisms in the LSJRB. However, the decline of emissions of metals and PAHs into the regional atmosphere in the last decade may improve conditions. PAH toxicity affects reproductive capacity of organisms and causes narcosis in fish. Metals typically cause a disruption of ion and water balance in aquatic organisms, leading to death. PCBs are present throughout the LSJRB at concentrations that may harm very sensitive organisms. PCBs have caused reproductive failure in numerous species. Older, banned pesticides are found throughout the basin, but they are usually at low levels that do not contribute substantially to the overall toxic stress on the river. The shipping areas of the river show elevated levels of PAHs while urban-industrial Jacksonville has

PAH and metal concentrations typical of other urban, industrial rivers. Other areas of concern include several tributaries with a history of industrial activity, which contain very high concentrations of multiple contaminants.

The Eighth State of the River Report is available in PDF format at http://www.sjrreport.com, along with a digital archive of cited references and previous editions of the report.

LIST OF ABBREVIATIONS AND ACRONYMS

AEF	American Eagle Foundation
AKA	Also Known As
ATSDR	Agency for Toxic Substances & Disease Registry
AWS	Alternate Water Supply
BMAP	Basin Management Action Plan
BOD	Biochemical Oxygen Demand
CCA	Chromated Copper Arsenate
CDC	Center for Disease Control
CDOM	Colored Dissolved Organic Material
CFR	Code of Federal Regulations
COJ	City of Jacksonville
CSA	Continental Shelf Associates
CWA	Clean Water Act
DDD	Dichlorodiphenyldichloroethane
DDE	Dichlorodiphenyldichloroethylene
DDT	Dichlorodiphenyltrichloroethane
DEP	Florida Department of Environmental Protection
DO	Dissolved Oxygen
DOM	Dissolved Organic Matter
DRI	Development of Regional Impact
EPA	U.S. Environmental Protection Agency
EPB	Jacksonville Environmental Protection Board
ESA	Endangered Species Act
FDHSMV	Florida Department of Highway Safety & Motor Vehicles
FDOH	Florida Department of Health
FDOT	Florida Department of Transportation
FLZ	Freshwater Lacustrine Zone
FWC	Florida Fish & Wildlife Conservation Commission
FWRI	Fish and Wildlife Research Institute
GDNR	Georgia Department of Natural Resources
GEA	Gross External Abnormalities
GIS	Geographic Information System
GSI	Gonadosomatic Index
HAB	Harmful Algal Bloom
HSDC	Highest Single Day Count (of Manatees)
HMW	High Molecular Weight
ICW	Intracoastal Waterway
JAXPORT	Port of Jacksonville, Florida
JIA	Jacksonville International Airport
JU	Jacksonville University
LDI	Landscape Development Intensity
LMW	Low Molecular Weight
LSJR	Lower St. Johns River
LSJRB	Lower St. Johns River Basin
MOL	Mitsui O.S.K. Lines
MPP	Manatee Protection Plan
MRZ	Mesohaline Riverine Zone
MS4	Municipal Separate Storm Sewer System
NAP	Non-Algal Particulates
NAS	Nonindigenous Aquatic Species
NAS JAX	Naval Air Station Jacksonville
NMFS	National Marine Fisheries Service
NOAA	National Oceanic & Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NRC	National Research Council
NPS	National Park Service
NTU	Nephelometric Turbidity Units
PAHs	Polyaromatic Hydrocarbons
PCBs	Polychlorinated Biphenyls
PCU	Platinum Cobalt Unit
PEL	Probable Effects Level
PLRG	Pollutant Load Reduction Goal
ppt	Parts per Thousand
OCPs	Organochlorine Pesticides
OLZ	Oligohaline Lacustrine Zone
SAV	Submerged Aquatic Vegetation
sd	Standard Deviation
SJR	St. Johns River
SSAC	Site-Specific Alternative Criteria
SJRWMD	St. Johns River Water Management District
STORET	STOrage and RETrieval (EPA Database)
SWIM	Surface Water Improvement and Management
TAC	Technical Advisory Committee
TEL	Threshold Effects Level
TMDL	Total Maximum Daily Load
TNC	The Nature Conservancy
TSI	Trophic State Index
UDS	Ulcerative Disease Syndrome
UNF	University of North Florida
USA	United States of America
USACE	U.S. Army Corps of Engineers
USCG	U.S. Coast Guard
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
USFWS	U.S. Fish and Wildlife Service
VSU	Valdosta State University
WBID	Waterbody Identifier
WHO	World Health Organization
WQC	Water Quality Criterion
WSEA	Jacksonville Water & Sewer Expansion Authority
WWII	World War II
WWTF	Waste Water Treatment Facility

Table of Contents

1. Background

1.1. Introduction to the River Report

This *State of the River Report for the Lower St. Johns River Basin* was written by a team of academic researchers from Jacksonville University (JU), University of North Florida (UNF) and Valdosta State University (VSU). This report has undergone an extensive review process including local stakeholders and an expert review panel with the expertise and experience in various disciplines to address the multi-faceted nature of the data.

The *State of the River Report* was funded through the Environmental Protection Board (EPB) of the City of Jacksonville, Florida, and the River Branch Foundation. The report comprises one component of a range of far-reaching efforts initiated by Jacksonville Mayors John Delaney and John Peyton and continued by Mayor Alvin Brown and the *River Accord* partners (including the St. Johns River Water Management District (SJRWMD), JEA, Jacksonville Water and Sewer Expansion Authority (WSEA; until 2011), and the Florida Department of Environmental Protection (DEP) to inform and educate the public regarding the status of the Lower St. Johns River Basin (LSJRB), Florida (Figure 1.1).

1.1.1. Purpose

The *State of the River Report's* purpose is to be a single clear, concise document that evaluates the current ecological status of the Lower St. Johns River Basin (LSJRB) based on a vast amount of scientific information.

1.1.2. Goals and Objectives

The overarching goal of the *State of the River Report* is to summarize the status and trends in the health of the LSJRB through comprehensive, unbiased, and scientific methods.

The tangible objectives of the report project include the design, creation, and distribution of a concise, easy-to-understand, and graphically pleasing document for the general public that explains the current health of the LSJRB in terms of water quality, fisheries, aquatic life, and contaminants.

Secondary objectives include the production of a baseline record of the status of the St. Johns River that can serve as a benchmark for the public to compare the future health of the river. This baseline information can be used by the public and policymakers to focus management efforts and resources on areas that need the most improvement first and to gauge the success of current and future management practices.

1.1.3. River Health Indicators and Evaluation

The *State of the River Report* describes the health of the LSJRB based on a number of broad indicators in four major categories:

- WATER QUALITY
  - Dissolved Oxygen (DO)
  - Nutrients (Nitrogen & Phosphorus)
  - Turbidity
  - Algal Blooms
  - Bacteria (Fecal Coliform)
  - Metals
  - Tributaries
  - Salinity
- FISHERIES
  - Finfish Fishery
  - Invertebrate Fishery
- AQUATIC LIFE
  - Submerged Aquatic Vegetation
  - Wetlands
  - Macroinvertebrates
  - Threatened and Endangered Species
  - Non-native Aquatic Species
- CONTAMINANTS
  - Toxics Release Inventory: Point Sources of Contaminants in the LSJR Region
  - Polyaromatic Hydrocarbons (PAHs)
  - Metals
  - Polychlorinated Biphenyls (PCBs)
  - Pesticides

The *State of the River Report* is based on the best available data for each river health indicator listed above. How each indicator contributes to, or signals, overall river health is discussed in terms of its 1) *Current Status,* and 2) the *Trend* over time.

The *Current Status* for each indicator is based on the most recent data and is designated as "satisfactory" or "unsatisfactory." In some cases, this designation is defined by whether the indicator meets state and federal minimum standards and guidelines.

The *Trend* is derived, where possible, from statistical analyses of the best available scientific data for each indicator and reflects historical change over the time period analyzed. The *Trend* ratings for each indicator are designated as "conditions improving," "conditions stable," "conditions worsening," or "uncertain." The *Trend* rating does not consider initiated or planned management efforts that have not yet had a direct impact on the indicator. Statistical tests to indicate trends vary with each indicator and are described in each section.

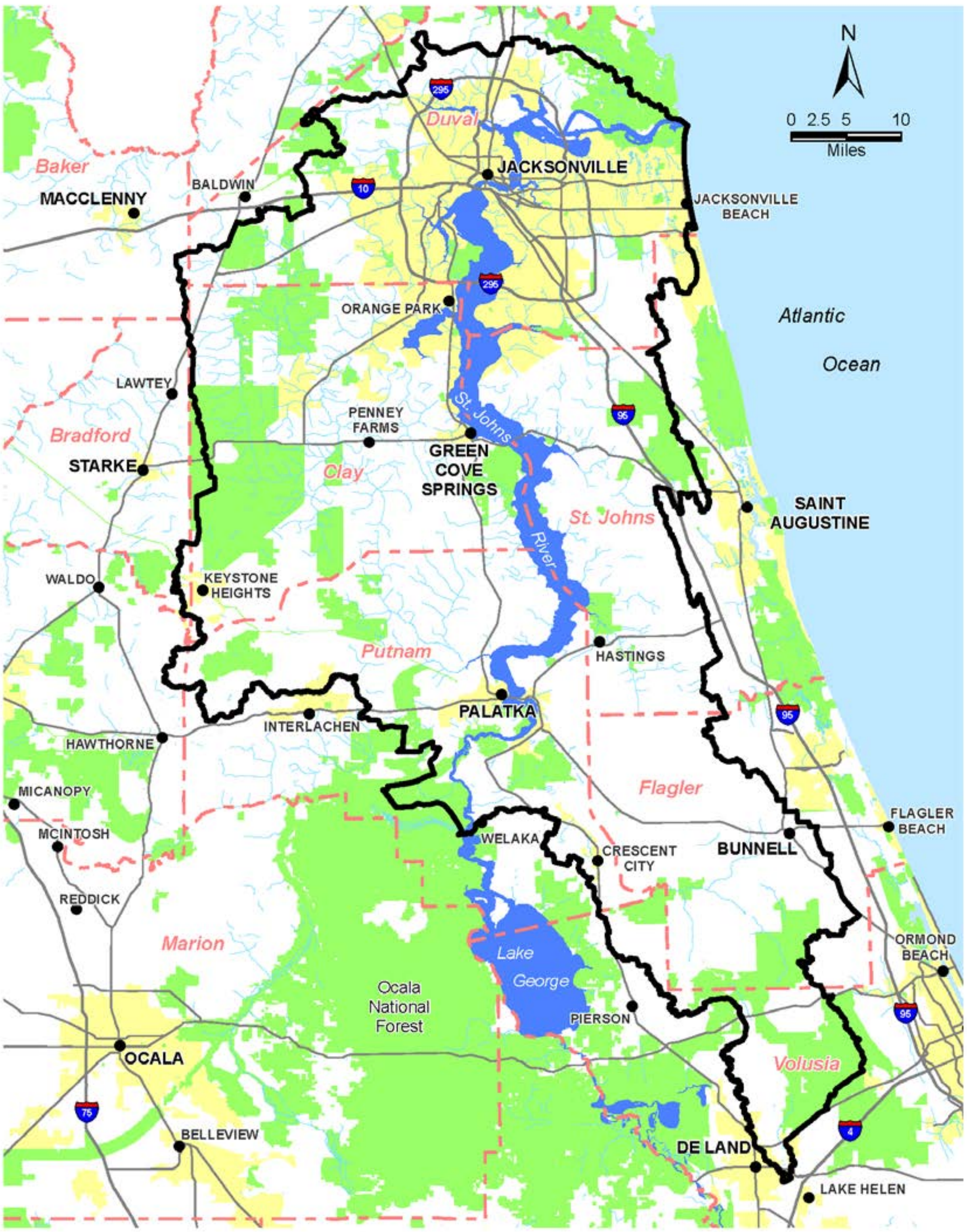


Figure 1.1 Geopolitical Map of the Lower St. Johns River Basin, Florida (outlined in black).

1.2. St. Johns River Basin Landscape

The LSJRB in Northeast Florida has long been recognized as a treasured watershed - providing enormous ecological, recreational, socioeconomic, and aesthetic benefits. However, during recent years, it has also been recognized as a threatened watershed, which is critically in need of resource conservation, water quality improvement, and careful management.

1.2.1. Geopolitical Boundaries

For management purposes, the entire St. Johns River watershed is commonly divided into five basins: the Upper Basin (southern, marshy headwaters in east central Florida), the Middle Basin (the area in central Florida where the river widens, forming Lakes Harney, Jesup, and Monroe), the Lake George Basin (the area between the confluence of the Wekiva River and St. Johns River and that of the Ocklawaha River and the St. Johns River), the Lower Basin (the area in Northeast Florida), and the Ocklawaha River Basin (the primary tributary for the St. Johns River). The LSJRB is the focus of this State of the River Report.

As a constant, this Report defines the LSJRB in accordance with the SJRWMD definition: "the drainage area for the portion of the St. Johns River extending from the confluence of the St. Johns and Ocklawaha rivers near Welaka to the mouth of the St. Johns River at Mayport" (**SJRWMD 2008**; Figure 1.1).

The LSJRB includes portions of nine counties: Clay, Duval, Flagler, Putnam, St. Johns, Volusia, Alachua, Baker, and Bradford (**Brody 1994**). Notable municipalities within the Lower Basin include Jacksonville, Orange Park, Green Cove Springs, and Palatka (Figure 1.1).

The LSJRB covers a 1.8 million-acre drainage area, extends 101 miles in length, and has a surface area of water approximately equal to 115 square miles (**Adamus, et al. 1997**; **Magley and Joyner 2008**).

1.2.2. Existing Land Uses

The LSJRB, including all aquatic and adjoining terrestrial habitats, consists of approximately 68% uplands and 32% wetlands and deepwater habitats (Figure 1.2, see Appendix 1.2.2.A. for acres and definitions of categories).

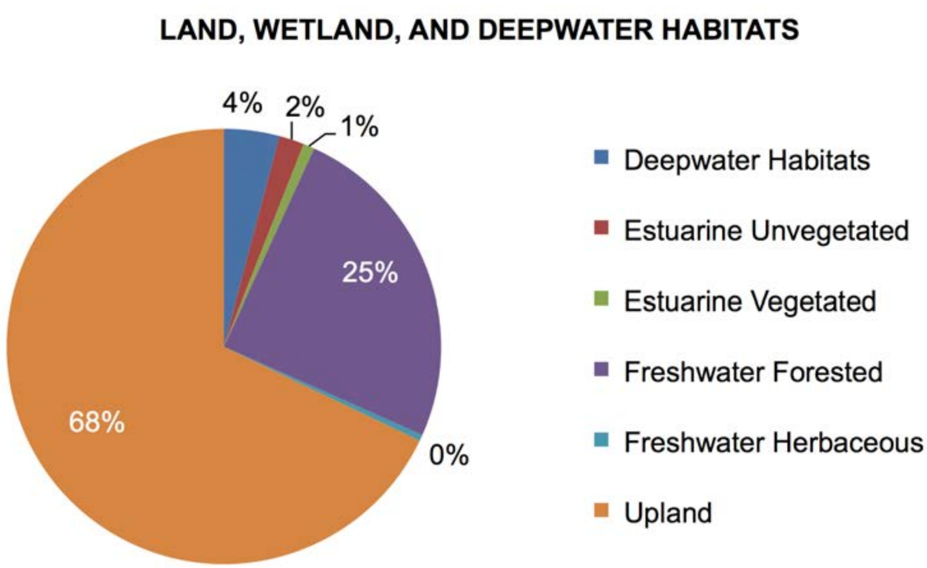


*Figure 1.2 Total percentages for land, wetland, and deepwater habitats within the Lower St. Johns River Basin, Florida. (Source: SJRWMD Wetlands and Deep Water Habitats GIS Maps, 1972-1980; **SJRWMD 2007b**)*

Within the LSJRB in 2004, the dominant land covers were upland forests (35%) and wetlands (24%), and 18% was considered urban and built-up. Since the 1970s, the proportion of the total basin designated as upland forests and agriculture has decreased, while the proportion designated as urban and built-up has increased (see Appendix 1.2.2.B.; **SJRWMD 2007b**).

1.2.3. Ecological Zones

The LSJRB is commonly divided into three ecological zones based on expected salinity differences (**Hendrickson and Konwinski 1998**; **Malecki, et al. 2004**). The ***mesohaline riverine zone*** is the most northern ecological zone in the LSJRB, stretching from the Atlantic Ocean to the Fuller Warren Bridge. The mesohaline riverine zone is typically deeper and well-mixed with an average salinity of 14.5 parts per thousand (ppt) and a fast flow rate. South of the Fuller Warren Bridge, the St. Johns River widens into a broad, shallow, slow-moving, tidal area called the ***oligohaline lacustrine zone***. This zone extends from the Fuller Warren Bridge to Doctors Lake and has an average salinity of 2.9 ppt. South of Doctors Lake to the confluence of the St. Johns and Ocklawaha rivers near Welaka, the LSJRB transitions into the ***freshwater lacustrine zone***. This zone stretches through the Middle and Upper Basins of the St. Johns River as well. The freshwater lacustrine zone is lake-like, has an average salinity of 0.5 ppt, and experiences tidal fluctuations that are lower than those observed in the other ecological zones.

1.2.4. Unique Physical Features

The St. Johns River is unique and distinctive due to a number of exceptional physical features.

The St. Johns River is the longest river in Florida. Stretching 310 miles and draining approximately 9,430 square miles, this extensive river basin drains about 16% of the total surface area of Florida (**DeMort 1990**; **Morris IV 1995**).

The St. Johns River flows northward. The result of this northward flow is that the *Upper* St. Johns actually lies south of the *Lower* St. Johns (**DeMort 1990**). The St. Johns River is one of the few rivers in North America to flow north.

The St. Johns River is one of the flattest major rivers in North America. The headwaters of the St. Johns River are less than 30 feet above sea level. The river flows downward on a slope ranging from as low as 0.002% (**Benke and Cushing 2005**) to about 1% (**DeMort 1990**). This slope is governed by the exceptionally flat terrain of the drainage basin and most of the decline occurs in the first 100 miles of the river. In fact, the river bottom at the mouth of Lake Harney is below sea level (**Bowman 2009**). This extremely low gradient contributes to a typically slow flow of the St. Johns River. This holds back drainage, slows flushing of pollutants, and intensifies flooding and pooling of water along the river creating numerous lakes and extensive wetlands throughout the drainage basin (**Durako, et al. 1988**). The retention time of the water, and its dissolved and suspended components, in the river is on the order of three to four months (**Benke and Cushing 2005**). High retention times of pollutants have severe impacts on water quality.

The Lower St. Johns River is a broad, shallow system. The average width of the Lower St. Johns River from Lake George to Mayport is one mile, although the flood plain reaches a maximum width of ten miles (**Miller 1998**). The average depth of the river is 11 feet (**Dame, et al. 2000**). The variability in width of the river can result in different water flow patterns and conditions on opposing banks of the river (**Welsh 2008**).

The St. Johns River receives saltwater from springs. Several naturally salty springs feed into the St. Johns River Drainage Basin. The most significant inputs of salty spring water originate from Blue Springs, Salt Springs, Silver Glen Springs, and Croaker Hole Spring (**Campbell 2009**). Inputs from these salty springs cause localized areas of elevated salinity (>5 ppt) in otherwise freshwater sections of the river (**Benke and Cushing 2005**). The amount of flow from springs is highly variable and dramatically affected by droughts (**Campbell 2009**).

The St. Johns River drains into the Atlantic Ocean. The average discharge of water at the mouth of the St. Johns River is 8,300 cubic feet per second (**Miller 1998**) or 5.4 billion gallons per day (**Steinbrecher 2008**). However, this flow rate is dwarfed by the volume of tidal flow at the mouth of the river, which is estimated to be approximately seven times greater than the freshwater discharge volume (**Anderson and Goolsby 1973**). This difference often causes "reverse flow," or a southward flow, up the river. Reverse flow has been detected as far south as Lake Monroe, 160 miles upstream, and is influenced as much by weather conditions as by ocean tides (**Durako, et al. 1988**). Natural water sources for the St. Johns River are direct rainfall, rainfall from runoff, underground aquifers, and springs. Continual input from springs and aquifers supplies the river with water that discharges into the Atlantic Ocean, despite drought periods or seasonal declines in rainfall (**Benke and Cushing 2005**). Water quality depends on the primary sources of water at any given time.

The salinity of the St. Johns River is heavily affected by seasonal rainfall patterns and episodic storm and drought events. In general, there is a predictable seasonal pattern of freshwater input from rainfall into the Lower St. Johns River, with the majority of rain falling during the wet season from June to October (**Rao, et al. 1989**). However, this seasonal pattern of rainfall can be overridden by less predictable, episodic storm events, i.e., hurricanes, tropical storms, or nor'easters, or drought events, like the droughts of the early 1970s, the early 1980s, 1989-1990, and 1999-2001 (**DEP 2010d**). In turn, surges of freshwater from heavy rainfall tend to reduce salinity levels in the river. Increased salinity occurs during periods of drought, when there is a deficit of fresh rainwater into the river. Thus, rainfall can prompt a chain of events in the river, where changes in salinity lead to impacts on aquatic plants and animals. Simplified examples of several sequenced events are illustrated below (Figure 1.3).

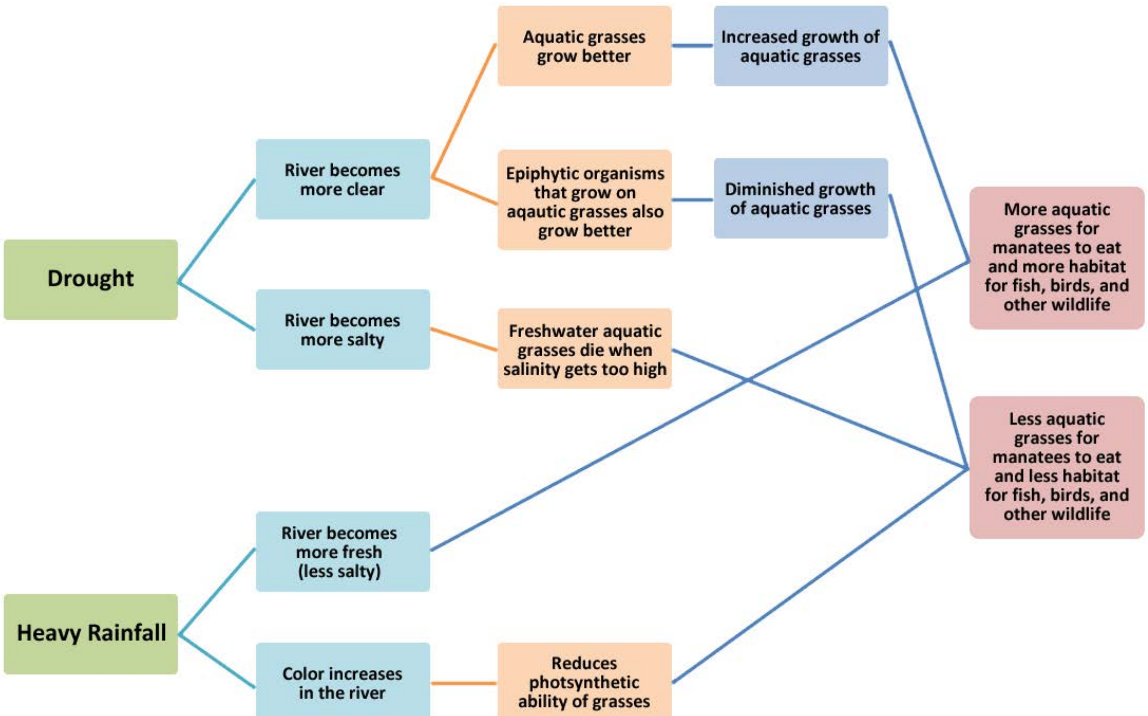


Figure 1.3 Simplified example of sequenced events that can occur in the Lower St. Johns River Basin stimulated by changes in rainfall.

The Lower St. Johns River is a tidal system with an extended estuary. The tidal range at the mouth of the river at Mayport, Florida is about six feet (**McCully 2006**). The Atlantic Ocean's tide heights are large compared to the slope of the St. Johns River, and at times, can produce strong tidal currents and mixing in the northernmost portion of the river. The St. Johns River is typically influenced by tides as far south as Lake George, 106 miles upstream (**Durako, et al. 1988**). During times of drought when little rainwater enters the system or extreme high tides, river flow-reversal can occur as far south as Lake Monroe, 160 miles upstream (**Durako, et al. 1988**). Tidal reverse flows occur daily in the LSJR, and net reverse flows, as much influenced by winds as by tides, can occur for weeks at a time (**Morris IV 1995**).

The St. Johns River can be influenced by local wind direction. Surface stress of local winds upon the river plays a secondary role compared with remote winds on the ocean that affect the river's flow. However, these local winds can cause flow enhancements. South winds blowing to the north accelerate the flow of water toward the ocean, if the flow is not opposed by a strong tidal current. Similarly, north winds can push river water back upstream (**Welsh 2008**). Strong sustained north winds from fall nor'easters or summer hurricanes can push saltwater up the river into areas that are usually fresh. Although considered a natural occurrence, reverse flow of the river can impact flora and fauna with low salinity tolerances and cause inland areas to flood.

The St. Johns River is a dark, blackwater river. Southern blackwater rivers are naturally colored by dissolved organic matter derived from their connections to swamps, where plant materials slowly decay and release these organic materials into the water (**Brody 1994**). The Dissolved Organic Matter (DOM) limits light penetration, and therefore photosynthesis, to a very shallow layer near the surface of the river.

1.3. Human Occupancy of the Region (pre-1800s)

1.3.1. Native Americans

The Lower Basin of the St. Johns River watershed has been occupied, utilized, and modified by humans for over 12,000 years (**Miller 1998**). As the Ice Age ended, the first Floridians were the Paleo Indians. They inhabited a dry, wide Florida hunting and gathering for food and searching for fresh water sources. Gradually, the glaciers melted, sea levels rose, and Florida was transformed. By approximately 3,000 years ago, the region resembled the Florida of today with a wet, mild climate and abundant freshwater lakes, rivers, and springs (**Purdum 2002**). The conditions were favorable for settlement, and early Indians occupied areas throughout the state. In fact, historians estimate that as many as 350,000 Native Americans were thriving in Florida (including 200,000 Timucua Indians in southeast Georgia and northern Florida), when the first French and Spanish explorers arrived in the 1500s (Figure 1.4; **Milanich 1995**; **Milanich 1997**).

The Native Americans that occupied much of the LSJRB were part of a larger group collectively known as the Timucua Indians. Actually a group of thirty or more chiefdoms sprinkled in villages throughout north Florida and southeastern Georgia, the Timucua Indians were bound to one another linguistically by a common language called Timucua (**Granberry 1956; Granberry 1993**). The Timucua language was spoken throughout the LSJRB north of Lake George and its tributary the Oklawaha River (**Milanich 1996**). By the 17th-century, the Spaniards living in the region referred to a distinct group of Timucua known as the Mocama (translates to "the sea") (**Ashley 2010**). The Mocama Indians spoke a unique dialect of the Timucua language called Mocama. They lived near the mouth of the St. Johns River and on the Sea Islands of southeastern Georgia and northeastern Florida (St. Simons, Jekyll, Cumberland and Amelia Islands) as far back as A.D. 1000 (**Worth and Thomas 1995**). Evidence has suggested that the Mocama had extensive trading networks that stretched as far west as the Mississippi River (**Ashley 2010**). Archaeological evidence also suggests that the Mocama became a permanent settlement and cultivated maize for food, in addition to traditional hunting and gathering (**Thunen 2010**). The Timucua Indians did modify the land to their advantage, such as burning and clearing land for agriculture and constructing drainage ditches and large shell middens (**Milanich 1998**). But, by today's standards, these impacts on the landscape were small in scale and spread out over a vast terrain.

The numbers of Native Americans in Florida plummeted during the 16th and 17th centuries, as many were killed by European diseases or conflicts (**Davis and Arsenault 2005**). By the 1700s, the original Timucua population in Florida had vanished (Figure 1.4).

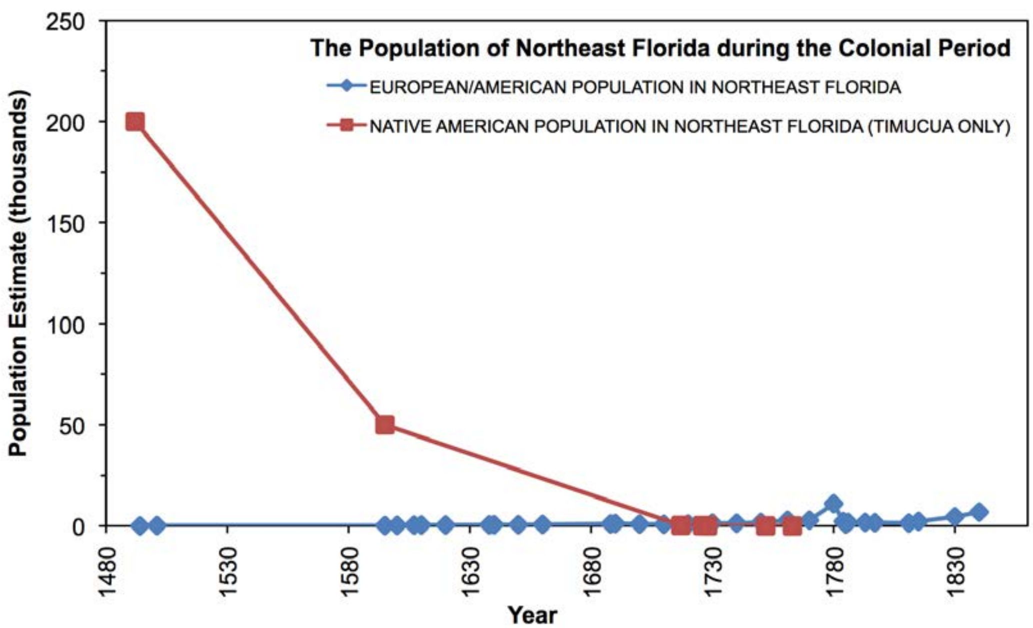


*Figure 1.4 Population of Northeast Florida during the Colonial Period, 1492 to 1845. (Sources: Population estimates for the Timucua Tribe in Northeast Florida were taken from **Milanich 1997**, and "Northeast Florida" is defined as all lands inhabited by Timucua Indians. Population estimates for European Colonists were taken from **Miller 1998**, and "Northeast Florida" loosely includes settlers in "the basin of the northward-flowing St. Johns River from Lake George to the mouth, as well as the adjacent Atlantic Coast and the intervening coastal plain" (**Miller 1998**). Complete data table provided in Appendix 1.3.1.*

1.3.2. Europeans

The first permanent European colony in North America was Fort Caroline, founded in 1564 by the French near the mouth of the St. Johns River (**Miller 1998**). One year later, the Spanish conquered the French, and from 1565 to 1763, the still-wild territory of Florida flew the flag of Spain (**Schafer 2007**). The epicenter of the Spanish colony became St. Augustine, and few colonists ventured beyond the walls of the guarded city. In retrospect, the footprint of these Spanish settlers on Florida was light. Apart from introducing non-native citrus, sugarcane, and pigs (the wild boars of today), they altered the environmental landscape very little along the St. Johns River watershed as compared to what was to come (**Warren 2005**; **Schafer 2007**).

In 1763, the British took control of Florida. Two years later, John Bartram, appointed as botanist to His Majesty George III of England, surveyed the natural resources of Florida that were now available for English use and benefit (**Stork 1769**). On this journey, John Bartram was accompanied by his son William, who would later become famous in his own right for discoveries recorded during his solitary travels through the southern colonies in the 1770's (**Bartram 1998**). The writings of this father and son provide evidence that the First Spanish Period left behind a wild and largely untouched land full of untapped resources and potential.

During the 20 years that the British occupied Florida, landscape modifications for colonization and agriculture were intensive. Large tracts of land were cleared for plantations intended for crop exportation, and timber was harvested and exported for the first time (**Miller 1998**). During the American Revolution, Florida became a haven for British loyalists, and the population of Florida ballooned from several thousand to 17,000 (**Milanich 1997**). The Spanish reacquired Florida in 1783, most of the British settlers left the area, and the state population declined again to several thousand (Figure 1.5). The Spanish continued plantation farming within the LSJRB, but did not exploit the land as successfully as the British (**Miller 1998**). Spain held Florida until the region was legally acquired by the United States in 1821. At this time, exploration and exploitation of the St. Johns River Basin began in earnest.

1.4. Early Environmental Management (1800s to 1970s)

The history of environmental management of the St. Johns River watershed, and water resources in Florida in general, is a complex, convoluted, but relatively short history. Major milestones in environmental management in Florida have taken place within just the last century, with much of the story occurring during our living memory (Table 1.1). The story of water management in Florida unfolds as a tale of lessons learned, a shift from reigning to restoring, from consuming to conserving.

Like the tides, management efforts in the watershed have surged and retracted over the last 100 years. Many landmark policies and programs have been initiated in response to environmental changes deemed intolerable by the public and the policymakers who represent them.

Noticeable, but small-scale, changes occurred in the St. Johns River Basin during pre-Columbian times, when Northeast Florida was occupied by the Timucua Indians (**Milanich 1998**). It was not until the Colonial Period, particularly during the British occupation in the late 1700s, that the environment experienced large-scale alterations. Such landscape modifications as the conversion of wetlands to agriculture and the clearing of forests for timber surged again in the mid-1800s after Florida was granted statehood (**Davis and Arsenault 2005**).

Most of the earliest changes to the landscape of the LSJRB were utilitarian in purpose, but the late 1800s and early 1900s were fraught with changes driven by the profitable, even whimsical, tourist industry. Tourists were fascinated with promotional accounts describing this land of eternal summer, filled with wild botanicals and beguiling beasts (**Miller 1998**). The growing village of Jacksonville became the initial portal to Florida, and a thriving tourist industry flourished as steamboats began to shuttle tourists up the St. Johns River. By 1875, Jacksonville was the most important town in Florida (**Blake 1980**). First tourists, and then developers and agricultural interests, were enticed to the rich and largely unexploited resource that was early Florida (**Blake 1980**). By the early 1900s, the population of Northeast Florida was increasing at a slow, steady rate (see Figure 1.5).

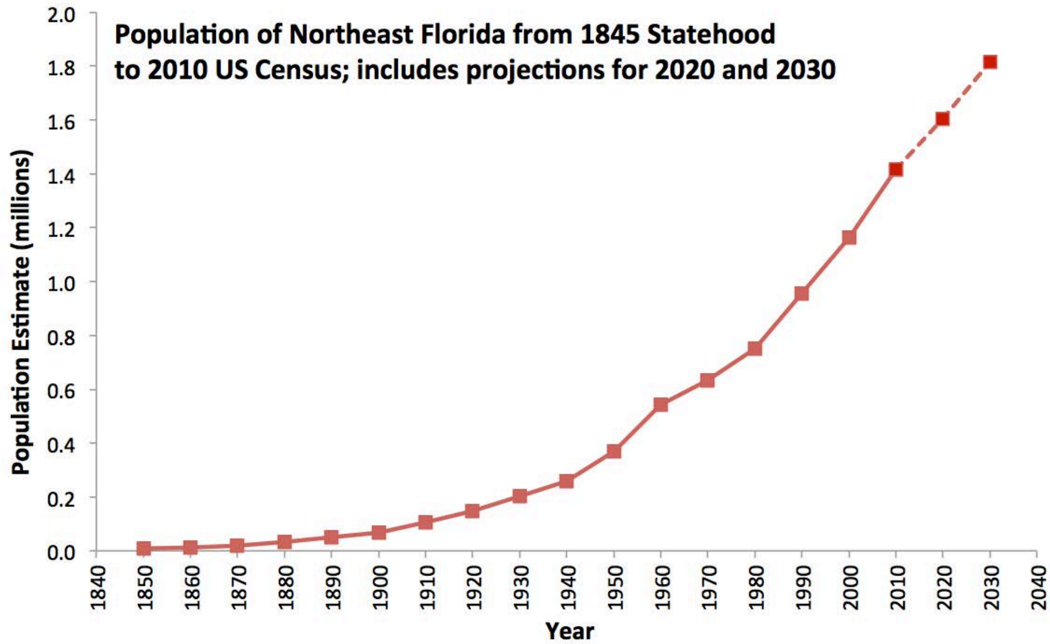


*Figure 1.5. Population of Northeast Florida from the time Florida was granted statehood to the 2010 U.S. Census including future population projections to 2030. ("Northeast Florida" includes population counts from Clay, Duval, Flagler, Putnam, and St. Johns counties. Sources: Population counts for the years 1850-1900 were provided by Miller 1998. Counts from 1900-1990 were extracted from **Forstall 1995**, and 2000 and 2010 counts from the USCB. (**USCB 2000; USCB 2010**) Note: U.S. Census data were not available for Flagler County in 1900 and 1910. Population estimates for 2020 and 2030 were extracted from the Demographic Estimating Conference Database (**EDR 2015**), updated August 2014.*

Impacts to the environment mirrored the steady population growth during the early 1900s. Entrepreneurs, investors, and government officials in Florida at this time were thoroughly focused on the drainage and redirection of water through engineering works (**Blake 1980**).

The immigration of new settlers was moderate during Florida's first century as a state, because the region still proved inhospitable and rather uninhabitable to the unadventurous. Not only was the region full of irritating, disease-carrying mosquitoes, Florida was just too hot and humid. But, that all changed when air conditioners for residential use became affordable and widespread after WWII (**Davis and Arsenault 2005**). Florida's population exploded around the 1950s and has continued to skyrocket ever since (**USCB 2000**; Figure 1.5).

By the 1960s, a century of topographical tinkering was taking its toll. Ecosystems across Florida were beginning to show signs of stress. Sinkholes emerged in Central Florida (the Upper Basin of the St. Johns River) indicating a serious decline in the water table (**SJRWMD 2010b**). Flooding, particularly during storm events, was destructive and devastating. Loss of wetlands peaked during this time, as wet areas were rapidly converted to agriculture or urban land uses (**Meindl 2005**). Water works, such as the Kissimmee Canal and Cross Florida Barge Canal, continued into the 1960s, but public opposition against such projects was mounting (**Purdum 2002**).

During 1970-71, Florida experienced its worst drought in history, and the attitudes toward water began to shift from control and consumption to conservation (**Purdum 2002**). During 1972, the "Year of the Environment," the Federal and State governments passed a number of significant pieces of environmental legislation (see Table 1.1). The laws of the early 1970s, such as the National Environmental Policy Act, Endangered Species Act, and Clean Water Act, showcased a change in our approach to resource use and our attitudes regarding ecosystem services, nature, and the environment. From this time forward, environmental management began to take a shift towards consideration of the outcomes of our actions.

The Clean Water Act (CWA) and its companion act, the Clean Air Act, have been some of the most enduring and influential pieces of legislation from the 1970s. The CWA addressed key elements that affect the long-term health of the nation's rivers and streams. The CWA requires states to submit a list of their "impaired" (polluted) waters to the U.S. Environmental Protection Agency (EPA) every two years (or the EPA will develop the list for them). States determine impairment primarily by assessing whether water bodies maintain certain categories of use, e.g. fishable and swimmable.

Whether a use is impacted or not is typically based on whether the water body meets specific chemical and biological standards or exhibits safety risks to people. Once a state has an approved or "verified 303(d)" list of impaired waters, it must develop a management plan to address the issues that are causing the impairment. This process of identifying and improving impaired waters through the CWA has played a major role in modern environmental management from the 1980s through the 2000s.

Table 1.1 Timeline of environmental milestones, Lower St. Johns River Basin, Florida: from European colonization to 2010s

DATE	EVENT
1765-1766	During the British occupation of Florida, John Bartram, the "Botanist to the King," and his son William Bartram toured the St. Johns River (**Davis and Arsenault 2005**).
1773-1777	Naturalist William Bartram chronicled his travels up the St. Johns River producing detailed descriptions of pre-statehood, Northeast Florida. "Bartram's observations remain an invaluable tool for environmental planning—restoring paradise—in northeastern Florida" (**Davis and Arsenault 2005**).
1821	Adams-Onis Treaty: United States legally acquired Florida (**Blake 1980**).
1835-1842	Second Seminole War: Many steamboats were first brought to the St. Johns River for combat with the Indians, but continued to operate out of Jacksonville for civilian purposes after the war (**Buker 1992**).
1845	Florida granted statehood.
1850	Swamp and Overflowed Lands Act: stated that Florida could have from the Federal government any swamp or submerged lands that they successfully drained (**Leal and Meiners 2002**).
1868	Florida's first water pollution law established a penalty for degrading springs and water supplies (**SJRWMD 2010b**).
1870-1884	Famed author of *Uncle Tom's Cabin*, Harriet Beecher Stowe, wintered in Mandarin and wrote essays extolling the beauties of the St. Johns River and attracting tourists to Florida (**Blake 1980**).
1870s	Increasing number of tourists visited Florida via steamboats up the St. Johns River.
1875	Jacksonville was the most important city in Florida (**Blake 1980**).
1880	Construction of jetties at the mouth of the St. Johns River was started in order to stabilize the entrance of the shipping channel. They were not finished until 1921 (**Davis 1925**).
1884	Water hyacinth introduced into the St. Johns River near Palatka (**McCann, et al. 1996**).
1895	The Port of Jacksonville shipping channel was deepened to 15-ft (**GLD&D 2001**).
1896	Water hyacinth had spread throughout most the LSJRB and was hindering steamboat navigation, causing changes in water quality and biotic communities by severely curtailing oxygen and light diffusion, and reducing water movement by 40-95% Palatka (**McCann, et al. 1996**).
1906	The Port of Jacksonville shipping channel was deepened to 24-ft (**GLD&D 2001**).
1912	Intracoastal Waterway from Jacksonville to Miami was completed (**SJRWMD 2010b**).
1916	The Port of Jacksonville shipping channel was deepened to 30-ft (**GLD&D 2001**).
1935	Cross-Florida Barge Canal construction was initiated.
1937	Federal government completed deepening of the St. Johns River to 30 feet deep from the ocean to Jacksonville.
1937	Construction was suspended on Cross-Florida Barge Canal.
1945	River and Harbor Act of 1945 authorized the construction of the Dames Point Fulton Cut. This 34-ft-deep cut-off channel eliminated bends in the shipping channel at Dames Point, Browns Creek and Fulton (St. Johns Bluff). The straightening of the channel shortened the distance between the City of Jacksonville and the ocean by about 1.9 miles.
1950s	Bacteria pollution was first documented in the St. Johns River (largely due to the direct discharge of untreated sewage into the river).
1952	The Port of Jacksonville shipping channel was deepened to 34-ft (**GLD&D 2001**).
1964	Construction continued on Cross-Florida Barge Canal.
1966-1967	Sinkholes occurring in Central Florida (within the Upper Basin of the St. Johns River) indicating a serious drop in the water table (**Purdum 2002**).
Dec. 5, 1967	The City of Jacksonville received a letter from the Florida Air and Water Pollution Control Commission and State Board of Health, who "ordered the City within 90 days to furnish plans and an implementation schedule to end the disposal of 15 million gallons per day of raw sewage into the St. Johns River and its tributaries" (**Crooks 2004**).
1967-1968	Voters approved the consolidation of the Jacksonville and Duval County local governments.
1968	Initial flooding of the Rodman Reservoir. The Rodman Dam was completed and dammed the lower Ocklawaha River.

1970	National Environmental Policy Act: required Federal agencies to consider the environmental impacts and reasonable alternatives of their proposed actions.
1970s	"Cleanup of the St. Johns River was impressive, but many of its tributaries remained heavily polluted; landfills were opened, but indiscriminate littering of wastes continued; polluting power plants and fertilizer factories closed, but other odors remained" (**Crooks 2004**). "Discharges occur to river of primary treated effluent or raw sewage. Periodic blue-green algal blooms and fish kills" (**DEP 2002**).
1970-1971	Florida experiences its worst drought in history (**Purdum 2002**).
1971	Construction stopped on Cross-Florida Barge Canal.
1972	Several federal and state environmental laws were passed. • Florida Water Resources Act: established regional water management districts and created a permit system for allocating water use (**Florida Legislature 1972a**). • Federal Clean Water Act: required that all U.S. waters be swimmable and fishable (**Congress 1972a**). • Land Conservation Act: authorized the sale of state bonds to purchase environmentally imperiled lands (**Florida Legislature 1972b**). • Environmental Land and Water Management Act: initiated the "Development of Regional Impact" program and the "Area of Critical State Concern" program (**Florida Legislature 1972b**). • Comprehensive Planning Act: called for the development of a state comprehensive plan (**Florida Legislature 1972c**). • Marine Mammal Protection Act: prohibited the killing or hurting of marine mammals in U.S. waters (**Congress 1972b**).
1973	Endangered Species Act: conservation of threatened and endangered plants and animals and their habitats (**Congress 1973**).
Mar. 1973	"Press release announced that the St. Johns River south of the Naval Air Station to the Duval County Line at Julington Creek had been deemed safe for water contact sports" (**Crooks 2004**).
1973-1974	The U.S. Army Corps of Engineers and DEP (then the Dept. of Natural Resources) implemented "maintenance control" of invasive aquatic plants (namely water hyacinth). Maintenance control replaced crisis management and kept water hyacinth populations at the lowest feasible level.
1977	The Federal government funded a shipping terminal on Blount Island (**Crooks 2004**).
1977	Seventy-seven sewage outfalls closed, and the St. Johns River became safe for recreational use again (**Crooks 2004**). Movement to regional wastewater treatment systems providing higher levels of treatment than before.
Jun. 18, 1977	St. Johns River Day Festival marked the completion of the St. Johns River cleanup, and there were reports of some types of aquatic life returning to the river (**Crooks 2004**).
1978	The Port of Jacksonville shipping channel was deepened to 38-ft (**GLD&D 2001**).
Mid - late 1980s	"Outbreak of Ulcerative Disease Syndrome in fish occurs from Lake George to mouth of river. Exhaustive studies are conducted, but specific cause is not determined" (**DEP 2002**).
1987	Surface Water Improvement and Management (SWIM) Act: Recognized the LSJRB as an area in need of special protection and restoration (**SJRWMD 2008**).
1987	Water Quality Attainment Plan adopted by City of Jacksonville City Council. The plan addressed causes and remedies for non-attainment of water quality criteria.
1988	"The Florida Department of Environmental Regulation delegated authority to permit dredging and filling of wetlands to the St. Johns River Water Management District" (**SJRWMD 2010b**).
1988	"With funding from the SWIM program, the St. Johns River Water Management District began restoration of the Upper Ocklawaha River Basin and the Lower St. Johns River Basin" (**SJRWMD 2010b**).
1989	SJRWMD publishes the first SWIM Plan for the LSJRB.
1990s	"Blue-green algal blooms occur in freshwater portion of the river" (**DEP 2002**).
1991	The Florida Times-Union began a monthly series of investigative reports entitled "A River in Decline." This series reported that 17% of septic tanks were failing. In 1990, 47% of tributaries failed to meet appropriate health standards for fecal coliform. In 1990, 50% of privately owned sewage treatment plants violated local regulations. 80% of pollutants in Jacksonville's waterways could be attributed to stormwater runoff (**Crooks 2004**).
Early 1990s	The Florida Department of Environmental Regulation "downgraded formerly pristine areas of Julington and Durbin Creeks in southern Duval County from GOOD to FAIR water quality due to stormwater, sewage, and other runoffs from the rapidly growing suburb of Mandarin." Half of the wetlands in this area were destroyed during this time period (**Crooks 2004**).
Late 1990s	Blooms of an exotic freshwater, toxin-producing, blue-green algae called *Cylindrospermopsis* occurred (**DEP 2002**).
1997	The Lower St. Johns River Basin Strategic Planning Session (the "River Summit") led to the development of a 5-year "River Agenda" plan.

1998	Several Florida environmental groups brought a lawsuit against the U.S. Environmental Protection Agency (EPA) for its failure to enforce the Total Maximum Daily Load (TMDL) provisions in the Federal CWA (*Florida Wildlife Federation, Inc., et al. v. Browner*, (N.D. Fla. 1998) (No. 4:98CV356). In 1999 the lawsuit against EPA was settled with a Consent Decree, which required EPA and the Florida Department of Environmental Protection (DEP) to begin implementation of the TMDL provisions of the CWA. The Consent Decree required EPA to establish TMDLs if the State of Florida does not (13-year schedule to establish TMDLs).
July 30, 1998	St. Johns River is designated as an American Heritage River (**DEP 2002**).
Sept. 17, 1998	DEP submitted the 1998 303(d) list of impaired water bodies to the EPA for approval. The 1998 303(d) list included 53 water bodies in the LSJR. The list was approved by EPA in November 1998.
1999	Florida legislature enacted the Watershed Restoration Act (Florida Statute Section 403.067) to provide for the establishment of TMDLs for pollutants of impaired waters as required by the Clean Water Act.
1999	DEP formed a local stakeholders group to review the TMDL model inputs.
April 26, 2001	Florida adopted a new science-based methodology to identify impaired waters as c. 62-303, F.A.C. (Identification of Impaired Surface Waters Rule).
June 10, 2002	Following an unsuccessful rule challenge by various individuals and environmental groups (Case No. 01-1332R, Florida Division of Administrative Hearings), the Impaired Surface Waters Rule (c. 62-303, F.A.C.) became effective.
July 2002	DEP appointed the Lower St. Johns River TMDL Executive Committee to advise the Department on the development of TMDLs and a Basin Management Action Plan (BMAP) for the nutrient impairments in the main stem of the LSJR.
Dec. 3, 2002	Four Florida environmental groups filed suit in federal court against the U. S. EPA for failure of EPA to approve/disapprove Florida's Impaired Waters Rule as being consistent with the CWA (*Florida Public Interest Research Group Citizen Lobby, Inc., et al., v U.S. EPA et al*.)
2002	The U.S. Army Corps of Engineers began the St. Johns River Harbor Deepening Project (**JAXPORT 2008**). The dredging project deepened "the outer 14 miles of the St. Johns River federal channel from the mouth of the river to Drummond Point" (**GLD&D 2001**). The channel was deepened to 41 ft. in areas where there is a limestone rock bottom. The main shipping channel is maintained at this depth presently.
2002	The hydrodynamic model for the LSJR Main Stem TMDL is completed.
2003	"River Summit 2003" takes place, and the River Agenda is revised.
Sept. 4, 2003	DEP determined that most of the freshwater and estuarine segments of the LSJR were impaired by nutrients, and a verified list of impaired waters for the LSJR was adopted by Secretarial Order.
Sept. 30, 2003	The nutrient TMDL for the LSJR was originally adopted by Florida (Rule 62-304.415, F.A.C.).
April 27, 2004	Florida's nutrient TMDL was initially approved by the EPA Region 4.
Aug. 18, 2004	St. Johns Riverkeeper and Linda Young (Southeast Clean Water Network) filed suit against the EPA on the basis that the targets upon which the TMDL were based were not consistent with the existing Class III marine dissolved oxygen criterion.
Oct. 21, 2004	EPA found that the nutrient TMDL for the LSJR did not implement the applicable water quality standards for dissolved oxygen and rescinded its previous approval of the nutrient TMDL for the LSJR.
May 24, 2005	The Executive Committee identified the water quality credit trading approach for the Basin Management Action Plan (BMAP).
Early fall 2005	Large clumps of surface scum, caused by the toxic blue-green algae *Microcystis aeruginosa*, bloomed from Lake George to Jacksonville. Some samples exceeded World Health Organization recommended guidelines (**SJRWMD 2010b**).
2005-2008	U.S. Army Corps of Engineers is extending the harbor deepening from Drummond Point to JAXPORT's Talleyrand Marine Terminal from 38 ft. to a maintained depth of 40 ft.
2006	Blooms of algae continue in the St. Johns River. "Algal blooms are caused by a combination of hot, overcast days, calm wind and excessive nutrients in the water, such as fertilizer runoff, stormwater runoff and wastewater" (**SJRWMD 2010b**).
Jan. 23, 2006	EPA established a new nutrient TMDL for the LSJR that would meet the dissolved oxygen criteria.
May 25, 2006	Site-Specific Alternative Criteria (SSAC) for dissolved oxygen in the LSJR (F.A.C. 62-302.800(5)) was adopted by the Florida Environmental Regulation Commission and submitted to the EPA for approval. The SSAC was developed by DEP in cooperation with the SJRWMD.
July 13, 2006	St. Johns Riverkeeper and Clean Water Network filed a suit in Federal Court challenging the EPA's approval of rule 62-302.800 (in effect, the SSAC). (*St. Johns Riverkeeper, Inc., et al. v. United States Environmental Protection Agency, et al.*, No. 4:2006cv00332 (N.D. Fla.))
July 2006	The River Accord: A Partnership for the St. Johns was established.
Sept. 2006	The project collection process for the LSJR Main Stem BMAP started, which provided the list of efforts that will implement the TMDL reductions and restore the river to water quality standards.
Oct. 10, 2006	EPA approved Site-Specific Alternative Criteria (SSAC) for dissolved oxygen in the marine portion of the St. Johns River.
2007	The U.S. Army Corps (USACE) started studying the impacts of blasting and dredging to deepen the navigation channel to a maintained 45 feet from the mouth of the river to Talleyrand Terminals (**USACE 2007**).

Feb. 1, 2007	The Executive Committee determined the LSJR Main Stem BMAP load allocation approach, which assigned reduction responsibilities to wastewater plants, industries, agriculture, cities and counties with urban stormwater sources, and military bases with stormwater sources.
April 2007	SJRWMD launched the public awareness initiative, “The St. Johns: It’s Your River,” in order to help the public understand their personal impacts to the river and their responsibility for the river’s condition (**SJRWMD 2010b**).
August 2007	Urban stormwater loads were identified and quantified by local jurisdictions for the LSJR Main Stem BMAP.
Jan. 17, 2008	EPA approves the LSJR nutrient TMDLs based on the recently adopted SSAC.
April 2, 2008	DEP revised the Surface Water Quality Standards (c. 62-302.530, F.A.C.) to match the EPA approved list of TMDLs for nutrients in the LSJR.
July 17, 2008	Earthjustice (representing the Florida Wildlife Federation, Conservancy of Southwest Florida, Environmental Confederation of Southwest Florida, St. Johns Riverkeeper, and Sierra Club) filed a lawsuit against the EPA “for failing to comply with their nondiscretionary duty to promptly set numeric nutrient criteria for the state of Florida as directed by section 303(c)(4)(B) of the Clean Water Act” (**Earthjustice 2008**; (*Florida Wildlife Federation, Inc., et al. v. Johnson et al.,* 4:2008cv00324 (N.D. Fla.)).
Aug. 6, 2008	The first annual “State of the River Report for the Lower St. Johns River Basin” was released by researchers at Jacksonville University and the University of North Florida.
August 2008	The LSJRB SWIM Plan Update was released. The plan was prepared by SJRWMD, Wildwood Consulting, Inc., and the Lower St. Johns River Technical Advisory Committee (TAC). The plan outlines milestones, strategies, and objectives to meet goals associated with water quality, biological health, sediment management, toxic contaminants remediation, public education, and intergovernmental coordination.
Sept. 17-18, 2008	SJRWMD held a technical symposium on the preliminary findings of studies examining the cumulative effects of proposed surface water withdrawals on the water resources of the St. Johns and Ocklawaha rivers. In October 2008, the National Research Council agreed to provide technical review of the SJRWMD’s assessment of potential cumulative impacts to the St. Johns River from proposed surface water withdrawals (**SJRWMD 2010b**).
Oct. 17, 2008	DEP finalized Lower St. Johns River Nutrients TMDL.
Oct. 27, 2008	The final Basin Management Action Plan (BMAP) for the Implementation of TMDLs for Nutrients was adopted by the DEP for the LSJRB Main Stem. The BMAP was developed by the Lower St. Johns River TMDL Executive Committee in cooperation with the DEP, SJRWMD, local industries, cities, counties, environmental groups, and many other stakeholders.
Jan. 16, 2009	EPA issued a formal determination under the CWA that numeric nutrient water quality criteria are necessary in Florida, and the DEP released plans to accelerate its efforts to adopt numeric nutrient criteria into State regulations.
May 19, 2009	DEP released FINAL Drafts of the LSJRB Group 2 Cycle 2 – Verified List and Delist List of Impaired Waters. These lists update the adopted 2004 303(d) master list of impaired waters.
July 2009	DEP adopts by rule fecal coliform TMDLs for 22 tributaries to the Lower St. Johns River.
November 2009	DEP adopts by rule several TMDLS: eight for fecal coliform, two for nutrients, five for dissolved oxygen and nutrient, one for dissolved oxygen, and two for lead.
Jan. 15, 2010	EPA provided amendments to DEP’s FINAL Drafts of the Lower St. Johns River Basin Group 2 Cycle 2 – Verified List and Delist List of Impaired Waters. These lists update the adopted 2004 303(d) master list of impaired waters.
May-December 2010	A major bloom of *Aphanizomenon* and a major fish kill with unusual characteristics occurred in early summer and these events were followed in mid-summer by an additional bloom of *Microcystis* and other cyanobacteria species and a second more typical fish kill. Massive drifts of an unusual, persistent foam occurred from mid-summer through the fall. Unusually high dolphin mortalities occurred May-September. NOAA designated LSJR dolphin mortalities during the summer of 2010 an Unusual Marine Mammal Mortality Event initiating a multi-agency task force to investigate the causes.
July 2010	FDEP adopts by rule five fecal coliform TMDLs for tributaries to the Lower St. Johns River.
Aug. 2010	The Lower St. Johns River Tributaries Basin Management Action Plan (BMAP), which addresses fecal coliform TMDLs for fifteen tributaries, was adopted. These fifteen tributaries include Craig Creek, McCoy Creek, Williamson Creek, Fishing Creek, Deep Bottom Creek, Moncrief Creek, Blockhouse Creek, Hopkins Creek, Cormorant Branch, Wills Branch, Sherman Creek, Greenfield Creek, Pottsburg Creek, Upper Trout River, and Lower Trout River. This plan was developed collaboratively by the City of Jacksonville, JEA, Duval County Health Department, Florida Department of Transportation, Tributary Assessment Team, the Basin Working Group Stakeholders, and the Florida Department of Environmental Protection (Tributary BMAP II - **DEP 2010b**).
Nov. 14, 2010	EPA Administrator Lisa P. Jackson signed final "Water Quality Standards for the State of Florida's Lakes and Flowing Waters" (inland waters rule). The final standards set numeric limits, or criteria, on the amount of nutrient pollution allowed in Florida's lakes, rivers, streams and springs. This rule is set to be effective March 6, 2012. On April 11, 2011, DEP requested EPA to withdraw its January 2009 determination that numeric nutrient criteria are necessary in Florida; to repeal November 2010 rulemaking establishing numeric criteria for inland streams, lakes, and springs; and to refrain from establishing any future numeric criteria. On June 13, EPA sent an initial response to FDEP’s petition. In their response, EPA is prepared to withdraw the federal inland standards if FDEP adopts, and EPA approves, their own protective and scientifically sound numeric standards. On March 5, 2012, EPA promulgated an extension of the effective date of the "Water Quality Standards for the State of Florida's Lakes and Flowing Waters" (inland waters rule) by four months to July 6, 2012. (The extension does not affect or change the February 4, 2011 date for the SSAC provision.) This extension affords the State additional time to finalize their own rule establishing numeric nutrient criteria for the State and submit it for EPA review. On November 30, 2012, EPA approves FDEP’s standards for numeric nutrient criteria in Florida’s flowing waters, springs, lakes, and South Florida estuaries, and in June 2013, EPA approves DEP’s criteria for estuaries and coastal waters. (**EPA 2013e**) In October 2014, EPA rescinds federally adopted criteria and DEP criteria are in effect.

Feb. – Apr. 2011	DEP released final TMDLS for Arlington River for nutrients; Mill Creek for dissolved oxygen and nutrients; and lead in Black Creek and Peters Creek.
May 10, 2011	SJRWMD issued to JEA a single consumptive use permit that consolidated 27 individual permits and allows groundwater withdrawals of up to 142 million gallons per day in 2012 and up to 155 million gallons per day in 2031 if key conditions are met.
July 2013	DEP begins an initiative to revise bacteria criteria for Florida's beaches and recreational waters. (**DEP 2014b**).
September 2013	EPA approves DEP's revised criteria for dissolved oxygen, which takes into account stream conditions and percent oxygen saturation. (**DEP 2013b).**
October 2013	DEP releases a final Florida Mercury TMDL (**DEP 2013a**).
January 2015	"St. Johns River Economic Study," edited by Dr. Courtney T. Hackney, is released to public. (**Hackney 2015a**)

1.5. Modern Environmental Management (1980s to 2000s)

The deluge of new environmental legislation in the 1970s caused a backlash during the 1980s from a property rights perspective (**Davis and Arsenault 2005**). At the same time, readily observable symptoms of environmental degradation continued to surface. The St. Johns River began having periodic blooms of blue-green algae, lesions in fish, and fish kills (**DEP 2002**). Each of these conditions was a visible expression of degraded water quality in the river and represented changes that were not acceptable to the public and policymakers.

Since the 1990s, water quality improvements have been achieved in Florida through the seesawing efforts of policymakers and public and private stakeholders (Table 1.1). The policymakers push on the legislative side (via governmental regulatory agencies), while public/private interests push on the judicial side (via lawsuits in the courts). The last two decades have been marked by this oscillation between lawsuits and laws. The result has been incremental and adaptive water quality management.

An important element of protecting the St. Johns River is the possession of a good understanding of the economic impact the river has on the region. To that end, the Florida Legislature in 2013 funded a report on the river's economic value to the state of Florida (**Hackney 2015a**). This report describes the economic impact of the St. Johns River in terms of a conceptual model relating natural functions with natural values, an assessment of wetland importance for flood prevention and nutrient removal, the effect on real estate values along or near the river, the importance of surface water in both water-use and water quality dimensions, and the impact of recreation and ecotourism.

1.6. Implementation of the Total Maximum Daily Load (TMDL) provisions of the Clean Water Act (CWA)

For years one aspect of the CWA was overlooked until an influential court decision in 1999. Several Florida environmental groups won a significant lawsuit against the EPA, pushing the agency to enforce the Total Maximum Daily Load (TMDL) provisions in the Federal CWA. For many water bodies, including the LSJR, the development and implementation of a TMDL is required by the CWA as a means to reverse water quality degradation. In the TMDL approach, state agencies must determine for each impaired water body: 1) the sources of the pollutants that could contribute to the impairment 2) the capacity of the water body to assimilate the pollutant without degradation and 3) how much pollutant from all possible sources, including future sources, can be allowed while attaining and maintaining compliance with water quality standards. From this information, agency scientists determine how much of a pollutant may be discharged by individual sources, and calculate how much of a load reduction is required by that source (Pollutant Load Reduction Goal or "PLRG"). Once the required load reductions are determined, then a Basin Management Action Plan ("BMAP") must be developed to implement those reductions. Monitoring programs must also be designed to evaluate the effectiveness of load reduction on water quality.

Since 1999, the EPA, DEP, SJRWMD, and numerous public and private stakeholders have been working through this TMDL/BMAP process to reduce pollution into the LSJR and its tributaries. Several TMDLs have been adopted in the LSJRB, including those for nutrients in the main stem and fecal coliforms in the tributaries. In most cases, adoption of TMDLs is followed by development of a BMAP. According to DEP, "the strategies developed in each BMAP are implemented into National Pollutant Discharge Elimination System (NPDES) permits for wastewater facilities and municipal separate storm sewer system (MS4) permits" (**DEP 2008c**). A main stem nutrient BMAP was completed in

October 2008. In December 2009, the DEP released the BMAP for fecal coliform in the Lower St. Johns River Tributaries (**DEP 2009d**). This BMAP addressed ten tributaries for which TMDLs had been adopted in 2006 and 2009: Newcastle Creek, Hogan Creek, Butcher Pen Creek, Miller Creek, Miramar Creek, Big Fishweir Creek, Deer Creek, Terrapin Creek, Goodbys Creek, and Open Creek (**DEP 2009d**). In August 2010, DEP released the second BMAP to address fecal coliform in fifteen LSJR tributaries (Tributary BMAP II **DEP 2010b**). Progress reports on all these BMAPs were published by DEP in 2014. As well, a new comprehensive statewide updated list of verified impaired waterbodies was released by DEP in 2014 (**DEP 2014c**).

Table 1.2 shows the number of 303(d) impairments in 2004, 2009, and 2014, along with delisted impairments in 2009 and 2014. The 2014 impairments are primarily due to a new mercury TMDL, dissolved oxygen, fecal coliform, and nutrients (**DEP 2015e**). Figure 1.6 illustrates the breakdown of the 2014 impairments. Table 1.2 also shows the number of 303(d) impairments that were delisted in 2009 and 2014. These delistings occurred for a variety of reasons, such as satisfying water quality criteria, or confirmation that natural conditions, not anthropogenic loading, caused the observed impairment.

DEP is developing new criteria for bacteria at beaches and other recreational waters. This process was initiated in July 2013 and is still underway.

Current and future efforts to improve the health of the LSJR (and other water bodies in Florida) will continue to focus on implementation of the TMDL provisions of the CWA. As this process presses forward, Florida's public and policymakers may continue to find themselves on the litigation-legislation seesaw, as both groups attempt to balance environmental concerns with an exploding population's desire to dwell and prosper in the Sunshine State.

1.7. Water Quality Credit Trading

In 2008, the Florida Legislature passed revisions to the Florida Watershed Restoration Act that established the framework for a system of water quality credit trading in the Lower St. Johns River Basin (**DEP 2010g**). This system allows individual dischargers of a pollutant, such as a local utility or a municipality, to trade credits for nutrients, which consist of total nitrogen and phosphorus. Each individual discharger has a goal for reduction of nutrients. Because some dischargers are able to control nutrients with a very different cost outlay than others, some dischargers meet and even exceed their goals, while others do not meet the goals. Thus those that exceed their goals possess "credits" that they can sell to those who do not meet their goals.

Prior to 2014, JEA exceeded its goal and was able to sell the accumulated credits. The City of Jacksonville has not met its goal. At the time of this writing, the City and JEA are developing an agreement by which JEA sells its credits to the City to temporarily meet its FDEP Surface Water Quality Improvement obligations by July 31, 2015. Response to this plan has been mixed. Some have expressed concerns that buying credits is an expenditure that does not actually improve the health of the river, while others have noted that the City has prioritized the St. Johns River in other ways, such as adding kayak access sites, creating the Groundwork Trust program, and continuing with septic tank programs. (**COJ 2014; Monroe 2015**).

Table 1.2 Summary of the verified 303(d) 2004, 2009, and 2014 lists of LSJR impaired water bodies or segments of water bodies requiring TMDLs.

YEAR	# IMPAIRMENTS	# WATER BODIES WITH IMPAIRMENT	# IMPAIRMENTS DELISTED	COMMENTS
2004	153	87		
2009	123	97	67	
2014 (draft)	239	151	167	Statewide mercury TMDL finalized in 2013, adding many WBIDs to impairment list.

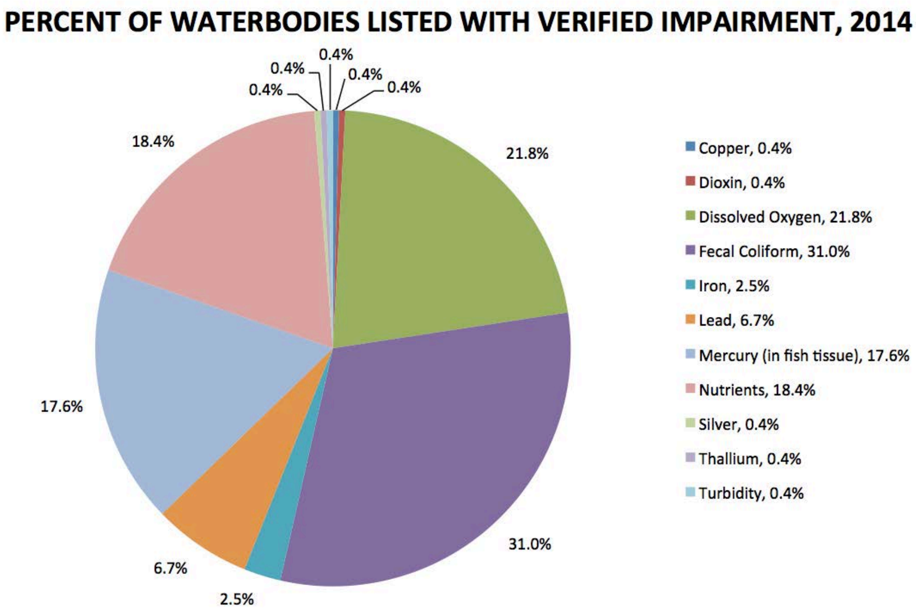


Figure 1.6 Percent of water bodies or segments of water bodies listed with various impairments in the Lower St. Johns River Basin in the 2014 verified list (as of April 7, 2015).

2. Water Quality

2.1. Overview

Water quality cannot be reduced to a single factor, much less a single number. Some parameters vary as a function of time or tide, others vary by depth, and still others change slowly with the seasons or do not have a consistent pattern of change. Despite these variations, similarities exist within segments of the mainstem of the LSJRB as well as among and within each tributary.

To identify characteristically similar segments in each separate water body, a unique water body identifier (WBID) number is assigned to each water body in the State. WBIDs offer an unambiguous method of referencing water bodies within the State of Florida. The mainstem of the LSJRB is divided into multiple segments, WBIDs 2213A through 2213N, that range from marine to freshwater systems. The section we refer to as marine/estuarine in this report spans from the mouth at WBID 2213A to WBID 2213G which contains Doctors Lake. The freshwater region extends from WBID 2213H upstream to WBID 2213N at the confluence of the Ocklawaha River (Figure 2.1).

The Clean Water Act mandates that each water body, each WBID, must be assessed for impairments for its stated uses. The LSJR is a Florida Class III water body, with designated uses of recreation, propagation, and maintenance of a healthy, well-balanced population of fish and wildlife. If a water body is determined to be impaired for its designated uses, a Total Maximum Daily Load (TMDL) must be established to set maximum allowable levels of pollutants that can be discharged into it that will allow it to achieve water quality standards.

In certain cases, the type and character of a water body may make it necessary to establish a special criterion for assessing the water quality of that water body. Florida's water quality standards also provide that a Site-Specific Alternative Criterion (SSAC) may be established where that alternative criterion is demonstrated, based on scientific methods, to protect existing and designated uses for a particular water body. As discussed in the background section and below, such a criterion has been established and EPA-approved for dissolved oxygen (DO) in the predominantly marine portion of the LSJRB.

The water quality of each segment of a river or tributary is strongly impacted by the land use surrounding the water body. Thus, the segments and tributaries of the LSJR vary in water quality impacts from agricultural, industrial, urban, suburban, and rural land uses. Often, different parts of the same stream will have changes in water quality that reflect changes in land use, industry and population along it. Identification of sources of nutrients or pollutants in the watershed of an impaired water body is part of the TMDL process and of the amount of pollutants discharged by each of these sources must be quantified.

Sources of pollutants are broadly classified as either "point sources" or "nonpoint sources". Historically, point sources are defined as discharges that typically have a continuous flow via a specific source such as a pipe. Domestic and industrial wastewater treatment facilities (WWTFs) are examples of point sources. Point sources are registered and permitted under the EPA's National Pollutant Discharge Elimination System (NPDES) program. Changes to the Clean Water Act made in 1987 included a redefinition that added storm water and drainage systems, which were previously considered nonpoint sources under the permitted NPDES program. The term "nonpoint sources" has been used to describe other intermittent, often rainfall-driven, diffuse sources of pollution, including runoff from urban land uses, runoff from agriculture, runoff from tree farming (silviculture), runoff from roads and suburban yards, discharges from failing septic systems, and even atmospheric dust and rain deposition. The Florida Legislature created the Surface Water Improvement and Management program (SWIM) as a way to manage and address nonpoint pollution sources. The program is outlined at **DEP 2008a**.

The required TMDL process for impaired waters considers and can require reductions to both these pollution source types in order to achieve water quality goals. For more about Florida's Watershed Management approach see **DEP 2010h**. In addition, a description of the Basin Management Action Plan (BMAP), which details actions to be taken in a specific basin, can be found at **DEP 2010f**. The status of Northeast District BMAP plans can be found at **DEP 2013f**.

The LSJRB mainstem BMAP was completed in 2008 (**DEP 2008b**) and a 5-year progress report on meeting the TMDL for nutrients was recently released in 2014 (**DEP 2014d**). There have been two BMAPs completed for a total of 25 tributaries in the lower basin (**DEP 2009d; DEP 2010b**) and progress reports on each were released in 2013 (**DEP 2013h; DEP 2013i**).

2.2. Dissolved Oxygen

2.2.1. Description and Significance: DO and BOD

DO is defined as the concentration of oxygen that is soluble in water at a given altitude and temperature (**Mortimer 1981**). The concentration of oxygen dissolved in water is far less than that in air; therefore, subtle changes may drastically impact the amount of oxygen available to support many aquatic plants and animals. The dynamics of oxygen distribution, particularly in inland waters, are essential to the distribution, growth, and behavior of aquatic organisms (**Wetzel 2001**). Many factors affect the DO in an aquatic system, several of them natural. Temperature, salinity, sediments and organic matter from erosion, runoff from agricultural and industrial sources, wastewater inputs, and excess nutrients from various sources may all potentially impact DO. In general, the more organic matter in a system, the less dissolved oxygen available. DO levels in a water body are dependent on physical, chemical, and biochemical characteristics (**Clesceri 1989**).

As discussed in Section 1, the St. Johns River is classified as a class III water body by the State of Florida. Until 2013, the class III Freshwater Quality Criterion (WQC) for DO has been 5.0 mg/L (62-302.530, F.A.C.; **DEP 2013j**), requiring that normal daily and seasonal fluctuations must be maintained above 5.0 mg/L to protect aquatic wildlife. The predominantly freshwater part of the LSJR extends north from the city of Palatka to the mouth of Julington Creek. The Florida DEP developed site specific alternative criteria (SSAC) for the predominantly marine portion of the LSJR between Julington Creek and the mouth of the river which requires that DO concentrations not drop below 4.0 mg/L. DO concentrations between 4.0 and 5.0 mg/L are considered acceptable over short time periods extending up to 55 days, provided that the DO average in a 24-hour period is not less than 5.0 mg/L (**DEP 2010a**).

In April, 2013, the U.S. EPA approved new DO and nutrient related water quality standards to be adopted by the Florida Environmental Regulation Commission (ERC). The revisions approved by the U.S. EPA include "revised statewide marine and freshwater DO criteria, anti-degradation considerations regarding any lowering of DO, protection from negative trends in DO levels, the inclusion of total phosphorus, total nitrogen, and chlorophyll *a* criteria for the Tidal Peace River, among other provisions relating to DO and nutrients". The State's revisions also require the protection of several federally listed threatened and endangered species, including three sturgeon and one mussel species.

Under the new revisions, in predominantly freshwaters of the SJR, the DO should not be less than 34 percent saturation, which is equivalent to approximately 2.6 mg/L at 30°C and 3.09 mg/L at 20°C (**DEP 2013k**). Additionally, in the portions of the LSJR inhabited by Shortnose or Atlantic Sturgeon, the DO should not be below 53 percent saturation, which is equivalent to approximately 4.81 mg/L at 20°C, during the months of February and March. After much assessment, the FDEP supported that maintaining the 5.0 mg/L minimum DO criterion in the location where spawning would occur should "assure no adverse effects on the Atlantic and shortnose sturgeon juveniles."

For predominantly marine waters, minimum DO saturation levels shall be as follows:

> *"1. The daily average percent DO saturation shall not be below 42 percent saturation in more than 10 percent of the values; 2. The seven-day average DO percent saturation shall not be below 51 percent more than once in any twelve week period; and 3. The 30-day average DO percent saturation shall not be below 56 percent more than once per year."*

For more information, please refer to the U.S. EPA decision document (**EPA 2013f**).

Additionally, seasonal limits for Type 1 SSAC were implemented in February 2014 for certain areas of the LSJR, where the default criteria in Rule 62-302.530, F.A.C. would apply during the other times of the year. For the Amelia River, the segment between the northern mouth of the river and the A1A crossing, a SSAC for DO has been set to 3.2 mg/L as a minimum during low tide from July 1st through September 30th, and not below 4.0 mg/L during all other conditions. Likewise, Thomas Creek (including tributaries from its headwaters to the downstream predominantly marine portion) has a SSAC for DO of 2.6 mg/L, with no more than 10 percent of the individual DO measurements below 1.6 mg/L on an annual basis.

This year's LSJR report includes data through 2014 (note that in some cases 2014 data were missing); therefore, the existing criteria for that time (older criteria) will be used to serve only for comparison. However, in future LSJR reports, DO values will be presented as percent saturation, and the newly implemented criteria will be used.

Biochemical oxygen demand (BOD) is an index of the biodegradable organics in a water body (**Clesceri 1989**). Simply, it is the amount of oxygen used by bacteria to break down detritus and other organic material at a specified temperature and duration. Higher BOD is generally accompanied by lower DO. The EPA suggests that the BOD not exceed values that cause DO to decrease below the criterion, nor should BOD be great enough to cause nuisance conditions (**DEP 2013j**).

Growth of bacteria and plankton requires nutrients such as carbon, nitrogen, phosphorus, and trace metals, in varying amounts. Nitrogen and phosphorus, in particular, may contribute to the overgrowth of phytoplankton, periphyton, and macrophytes, which then in turn senesce. Therefore, nutrient inputs into the river can increase the BOD, thereby decreasing the DO. Phytoplankton population responses to the increased nutrients in a system may be only temporary. However, if nutrient inputs are sustained for long periods, oxygen distribution will change, and the overall productivity of the water body can be altered (**Wetzel 2001**).

2.2.2. *Factors that Affect DO and BOD*

Warmer temperatures influence DO by decreasing its solubility (**Mortimer 1981**). Increasing temperatures also increase metabolism by causing an increase in respiration in aquatic organisms, which is a process that requires oxygen. Increased metabolism and production of bacteria and phytoplankton contribute to a higher BOD. Therefore, when the temperature increases, the BOD increases in the environment, and DO availability is reduced. Shallow areas and tributaries of the LSJR that are without shade have particularly elevated temperatures in the summer months. Correspondingly, DO concentration decreases during those times. The DO changes are compounded in waters with little movement, so turbulence is also a pertinent parameter in the system. Turbulence causes more water to come in contact with the air and thus more oxygen mixes and diffuses into the water from the atmosphere.

Salinity is another factor that affects DO concentrations in the LSJRB. Salt reduces oxygen solubility causing lower DO in aquatic systems. Normal seawater has about 20% less oxygen than freshwater (**Green and Carritt 1967**; **Weiss 1970**). Factors influencing DO, such as increasing temperatures and BOD, will be compounded in saltwater as compared to freshwater.

Furthermore, productivity and sediment type can also influence the DO concentration. DO usually exhibits a diurnal (24-hour) pattern in eutrophic or highly productive aquatic systems. This pattern is the result of plant photosynthesis during the day, which produces oxygen; such that the maximum DO concentration will be observed following peak productivity, often occurring just prior to sunset. Conversely, at night, plants respire and consume oxygen, resulting in an oxygen minimum, which often occurs, just before sunrise (**Laane, et al. 1985**; **Wetzel and Likens 2000**). The LSJR is highly productive; however, as discussed above, it is a blackwater river, and photosynthesis by submerged aquatic vegetation is limited. In addition to the diurnal DO cycle described, bacterial oxygen demand generally dominates following algal blooms due to decomposition processes, and is present both during the day and the night.

Trophic state is an indicator of the productivity and balance of the food chain in an ecosystem. A good discussion of trophic state is found on the website of the Institute of Food and Agricultural Sciences at the University of Florida (**IFAS 2009**). High TSI values can indicate high primary (plant) productivity; however, these values can also be indicative of an unbalanced ecosystem, with increased nutrients and algal biomass, which can result in large fluctuations in DO.

2.2.3. *Data Sources*

All data used for the DO and BOD analyses were from the Florida DEP STOrage and RETrieval (STORET) database. STORET is a computerized environmental data system containing water quality, biological, and physical data. DO and BOD were measured using methods EPA 360.1 and EPA 405.1, respectively. From the data sets, negative values were removed. Values designated as present below the quantitation limit (QL) were replaced with the "actual value" if provided, or replaced with the average of the method detection limit (MDL) and practical quantitation limit (PQL) if the "actual value" was not provided. For "non-detect" values and values designated as "zero" half of the MDL was used. This section examines the data from the freshwater part of the mainstem (WBID 2213H-N), the predominantly saltwater part of the mainstem (WBID 2213A-G), as well as the entire LSJRB (Figure 2.1) and not solely the tributaries (discussed in Section 2.8).

Data are presented in box and whisker plots, which consist of a five number summary including: a minimum value; value at the first quartile; the median value; the value at the third quartile; and the maximum value. The size of the box is a measure of the spread of the data with the minimum and maximum values indicated by the whiskers. The median value is the value of the data that splits the data in half and is indicated by the horizontal blue line in the center of the boxes.

2.2.4. *Limitations*

The time of day in which water quality is measured can strongly influence the result due to the diurnal pattern of DO. Additionally, some of the more historic data lacks pertinent corresponding water quality characteristics, such as tides, which may have impacted the measurements.

2.2.5. *Current Status and Trends*

The majority of the DO values in the LSJRB from 1997 to 2014 were above WQC and therefore within acceptable limits (Figure 2.2A-C). The median values have been stable the last three years; however, minimum DO concentrations were well below WQC, particularly in freshwater areas, and therefore may threaten resident aquatic life (Figure 2.2A-C). Minimum DO concentrations increased in saltwater areas of the LSJR mainstem in 2013 (data were unavailable in 2014), demonstrating improved conditions; however, other areas of the LSJR, particularly tributaries, remain potentially problematic with lower DO levels (Figure 2.2A-C). Yearly data alone can be misleading. A clear seasonal trend is demonstrated in the entire LSJR, the freshwater, and the saltwater areas of the mainstem (Figure 2.3A-C), with the lowest concentrations observed in the summer months, particularly August and September. Seasonal DO fluctuation was most problematic in the tributaries and creeks, where the lowest DO concentrations were observed. In summer months, several DO values were below the site-specific minimum standard of 4.0 mg/L as well as the newly implemented criteria. It is likely that the aquatic life inhabiting the freshwater areas of the mainstem, as well as the tributaries and creeks will be more affected by low DO events during this time. Water quality conditions in tributaries will be addressed separately in Section 2.8 because DO concentrations can vary among tributaries, depending on the surrounding land use, water flow, and depth. Since 2010, the median BOD values in the LSJR mainstem (particularly freshwater areas) have been relatively stable (Figure 2.4). The median and maximum BOD values have decreased since 2011 in the predominantly saltwater areas (Figure 2.4C), coinciding with increased DO values. A seasonal pattern of increased BOD values was observed in the LSRJ mainstem, especially in freshwater areas, with the highest values observed in summer months (2.5A-C). Taking everything into account, the current overall STATUS is *unsatisfactory (dependent on location, time of day, and season)* the TREND is *unchanged* for the freshwater areas of the mainstem, *improving* in the saltwater areas of the mainstem, and *worsening* for the tributaries.

2.2.6. *Future Outlook*

Analysis of available data indicates that the average DO levels in the LSJRB are generally within acceptable limits; however, unacceptable DO concentrations occurred intermittently during every month of the year. Low DO was most problematic during summer months with many of the lowest measurements occurring in tributaries and creeks. DO concentrations below 5.0 mg/L for prolonged periods may be too low to support the many aquatic animals that require oxygen (**EPA 2002b**; **EPA 2002a**). Maintenance above minimum DO levels is critical to the health of the St. Johns River and organisms that depend on it. Nutrient reduction strategies, discussed in the next section, have recently been devised by government agencies and may combat the low DO concentrations observed in the LSJR to some extent. Additionally, monitoring agencies are now making efforts to collect data that better represent the variable DO conditions and to concurrently document other important water quality characteristics for an improved assessment of the river's health.

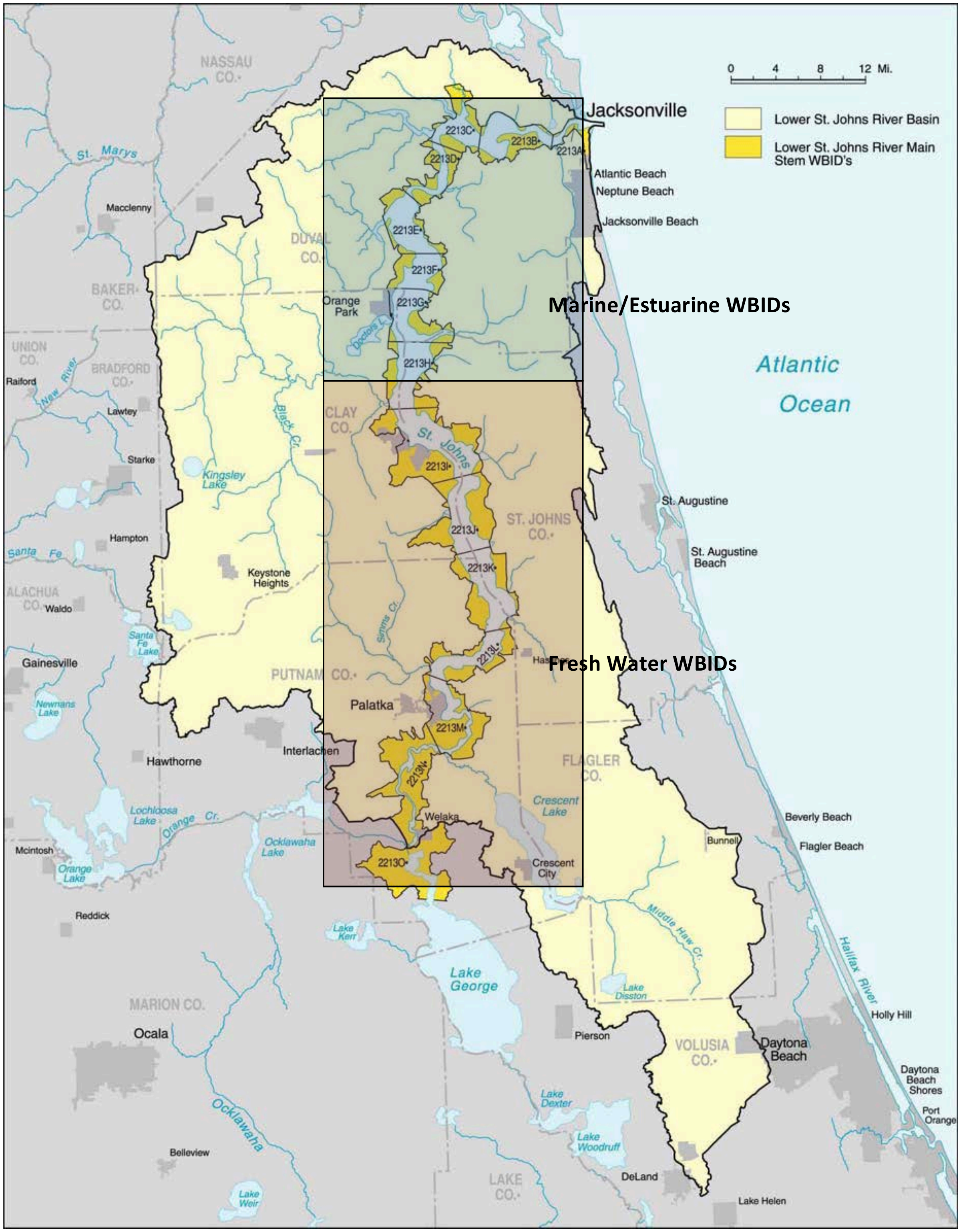


*Figure 2.1 Lower St. Johns River Mainstem Water Body Identification (WBID) Numbers (Figure 3, p5 in **Magley and Joyner 2008**) with designations of marine/estuarine WBIDs and freshwater WBIDs as used in this report.*

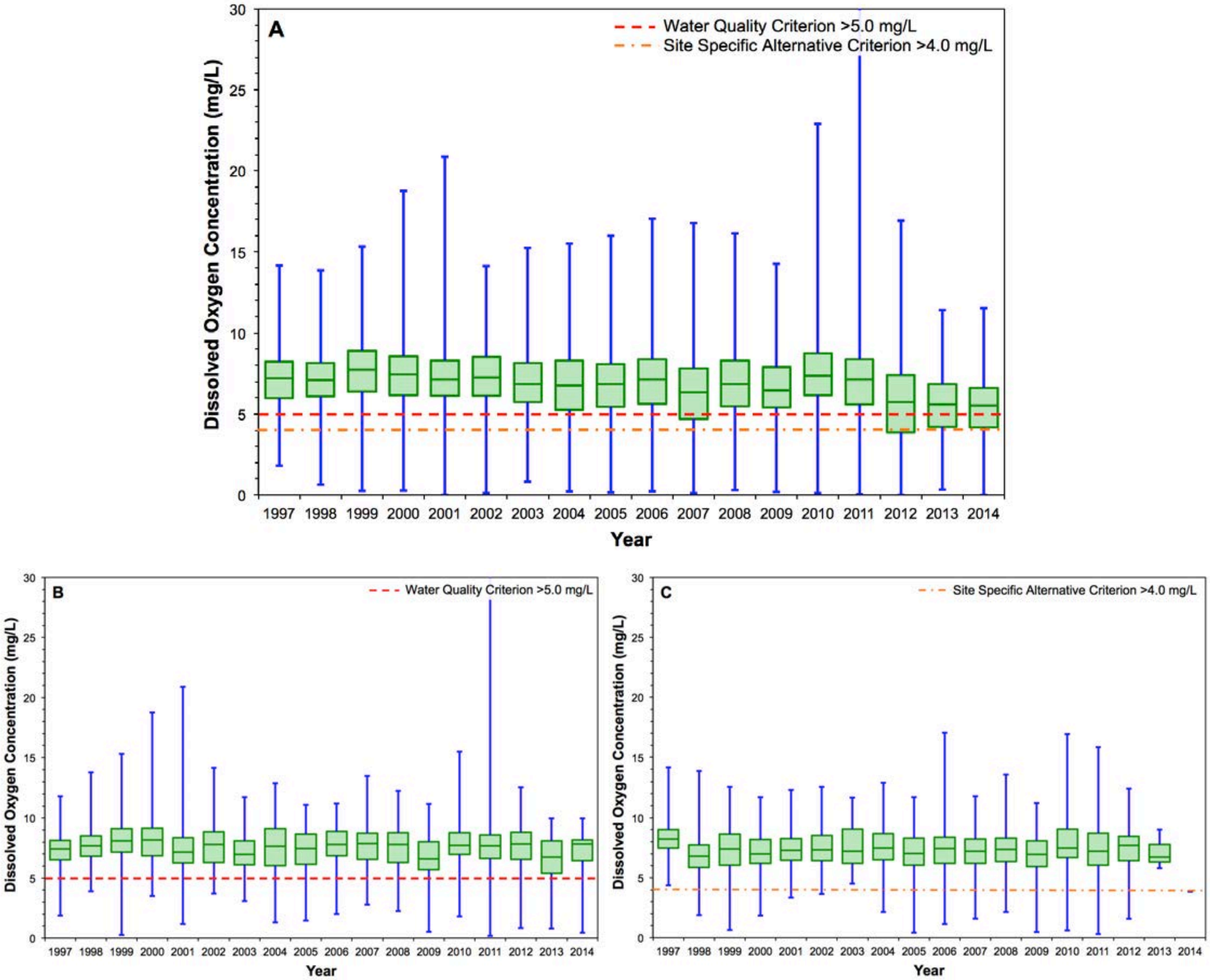


Figure 2.2 Yearly DO from 1997 to 2014 in A., the entire LSJR, B., the freshwater portion of the LSJR mainstem, and C, the predominantly saltwater portion of the LSJR mainstem. Data are presented as a box-and-whiskers plot with the green boxes indicating the median ±25% (middle 50% of the data) and horizontal lines indicate the median values. Blue whiskers indicate the minimum and maximum values in the data set.

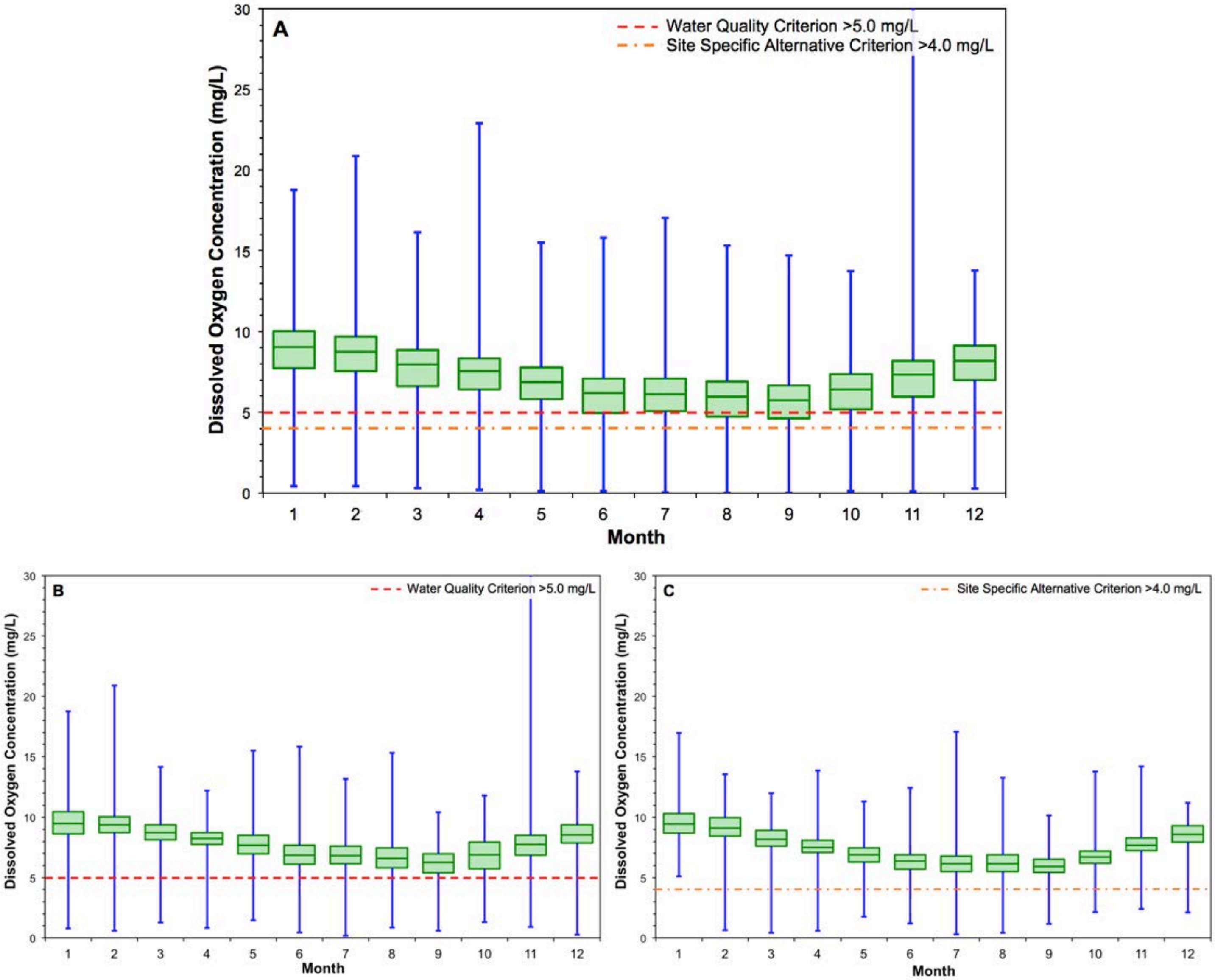


Figure 2.3 Monthly DO concentrations from 1982 to 2014 in A., the entire LSJR, B., the freshwater portion of the LSJR mainstem, and C, the predominantly saltwater portion of the LSJR mainstem. Data are presented as a box-and-whiskers plot with green boxes indicating the median ±25% (middle 50% of the data) and horizontal lines indicating the median values. Blue whiskers indicate the minimum and maximum values in the data set.

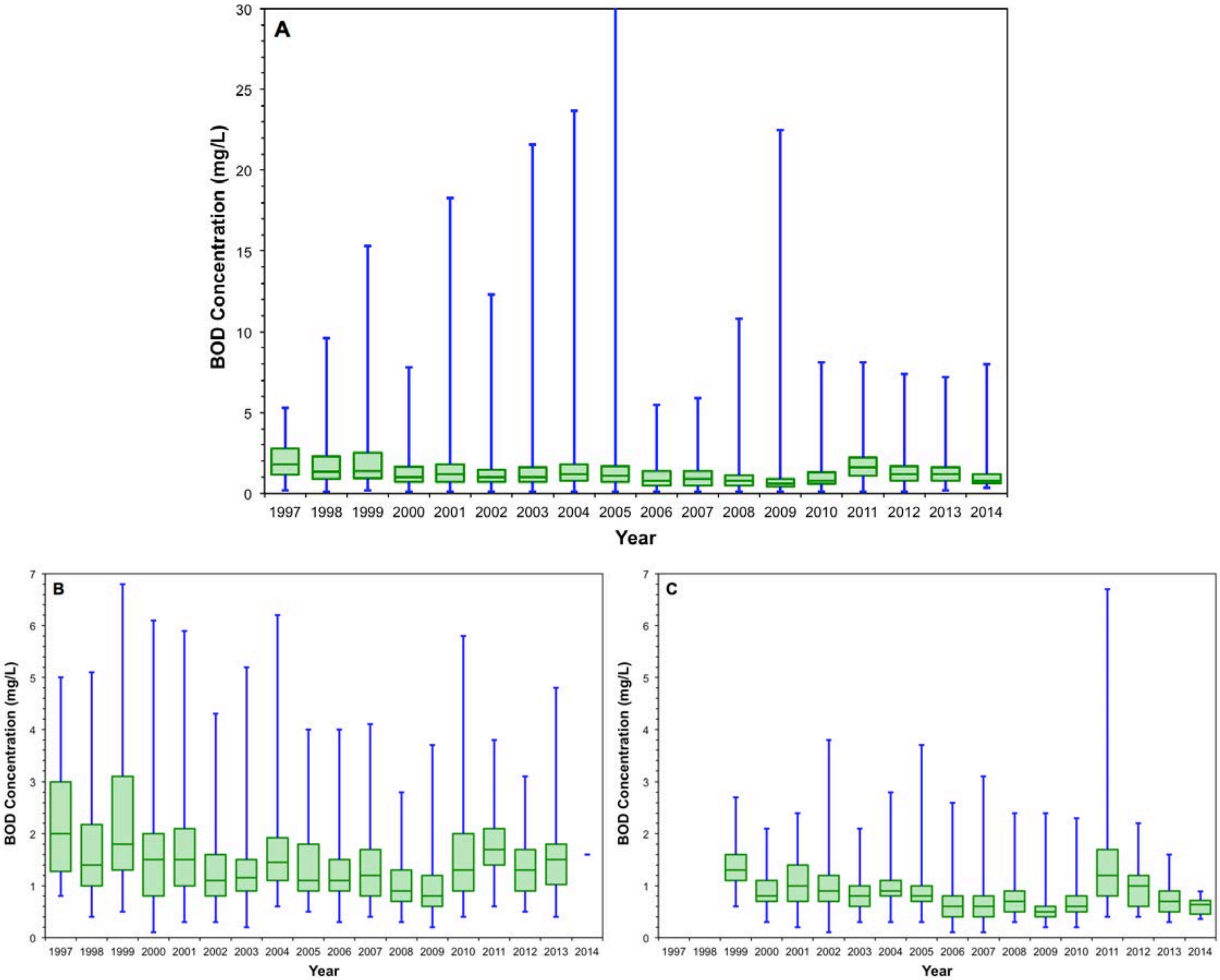


Figure 2.4 Yearly biochemical oxygen demand from 1997 to 2014 in A., the entire LSJR, B., the freshwater portion of the LSJR mainstem, and C, the predominantly saltwater portion of the LSJR mainstem. Data are presented as a box-and-whiskers plot with green boxes indicating the median ±25% (middle 50% of the data) and horizontal lines indicating the median values. Blue whiskers indicate the minimum and maximum values in the data set.

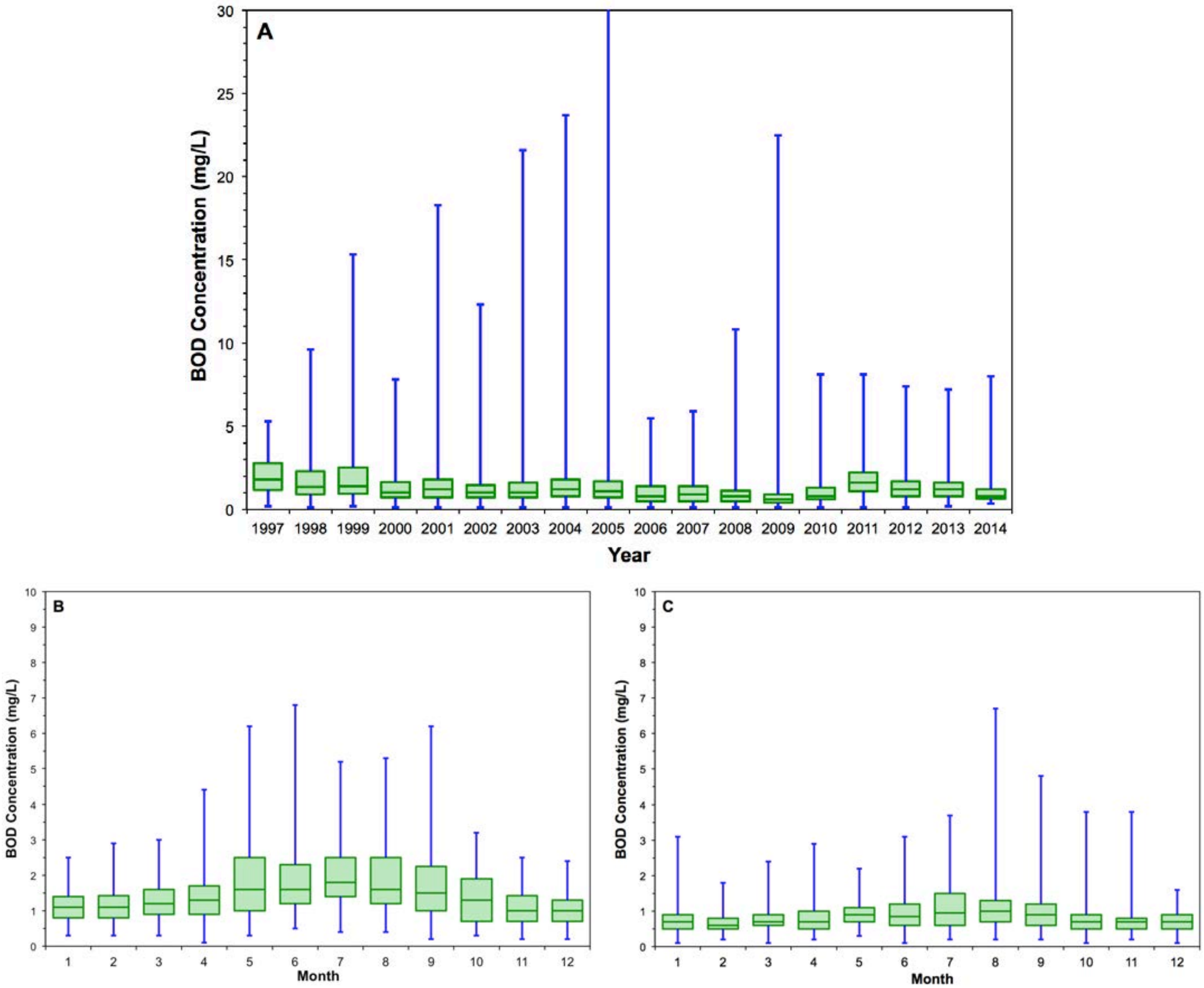


Figure 2.5 Monthly biochemical oxygen demand from 1997 to 2014 in A., the entire LSJR, B., the freshwater portion of the LSJR mainstem, and C, the predominantly saltwater portion of the LSJR mainstem. Data are presented as a box-and-whiskers plot with the green boxes indicating the median ±25% (middle 50% of the data) and horizontal lines indicate the median values. Blue whiskers indicate the minimum and maximum values in the data set.

2.3. Nutrients

Phosphorus and nitrogen are important and required nutrients for terrestrial and aquatic plants, including algae. Under optimal conditions, nutrients can stimulate immediate algal growth. Alternatively, if absent, nutrients can limit algal abundance. If the nutrient concentrations in a system remain high for extended periods of time, eutrophic conditions may result, potentially changing the entire ecosystem by favoring the growth of some organisms and changing the optimal water quality conditions for other organisms. The term “eutrophic” generally signifies a nutrient-rich condition, resulting in a high concentration of phytoplankton (**Naumann 1929**). The more recent definition characterizes eutrophication as an increase in organic matter loading to a system (**Nixon 1995**). Eutrophication is a natural process, predominantly occurring in small, enclosed water bodies like ponds and lakes. However, anthropogenic (man-made) activities that increase the loading of nutrients into a waterway can greatly increase the level of eutrophication, even in rivers such as the Lower St. Johns River and its tributaries.

2.3.1. Description and Significance: Nitrogen

Forms of nitrogen typically found in water bodies include nitrate, ammonia and organic nitrogen. These different forms convert to each other in organisms and in the environment (**Wright and Nebel 2008**). While the atmosphere contains 78%

nitrogen gas by volume, this form of nitrogen is unreactive and unavailable to most organisms. An exception is "nitrogen-fixers." These bacteria take up nitrogen from the atmosphere, and convert it to forms usable by other organisms. Nitrogen-fixers can add significantly to the overall nitrogen loading to a system.

Nitrate is one of the most bioavailable forms of nitrogen and can be rapidly taken up by plants. Sources of nitrate in waterbodies include atmospheric deposition, stormwater runoff containing fertilizer from agriculture and residential areas, runoff from animal operations, and poorly treated sanitary wastewater. In particular, failing septic tanks contribute to nitrate contamination of shallow groundwaters and surrounding water bodies (**Harrington, et al. 2010**). Nitrite and nitrate are converted from one to the other by microbes, depending on the availability of oxygen and the pH of the environment. Under typical environmental conditions nitrite concentrations are very low compared to nitrate. Generally, both nitrate and nitrite are measured together and the values reported as nitrate plus nitrite.

Ammonia is also taken up by phytoplankton (**Dortch 1990**) and is often converted to nitrate under the correct conditions. It is a waste product of aquatic organisms and naturally occurs in surface and wastewaters at concentrations ranging from 0.010 mg/L in some natural surface waters and groundwater, to 30 mg/L in some wastewaters (**Clesceri 1989**). Organic nitrogen such as proteins and urea, can decompose to ammonia (**Hutchinson 1944; Wetzel 2001**).

Total ammonia consists of two forms: un-ionized ammonia (NH_3) and ammonium ion (NH_4^+). They interconvert depending on environmental pH, temperature and salinity. High pH, high temperature and low salinity promote formation of the more toxic form, un-ionized ammonia. It is more toxic to aquatic organisms because of its ability to cross biological membranes.

Other human sources of nitrogen compounds primarily include industrial fixation in the manufacturing of fertilizers, and the combustion of fossil fuels which liberates nitrogen oxides into the atmosphere. The form of nitrogen that enters a waterway can give an indication of its source. However, as noted above, in aquatic systems several abiotic and biotic processes can change the form of nitrogen, so the source may not be as easily identified. Abiotic processes include acid-base reactions and complexation; biotic processes include nitrification, denitrification, and nitrogen fixation. Sediments may act also as a major reservoir of nitrogen, just as they do for phosphorus (**Levine and Schindler 1992**).

Unbalanced total nitrogen levels in a system can have severe impacts on the distribution of phytoplankton and the zooplankton that eat it. Excess nitrogen can markedly increase some types of phytoplankton. Others, such as some cyanobacteria, thrive in low-nitrogen conditions because they can convert inert atmospheric nitrogen to reactive nitrogen, which allows them to grow rapidly and outcompete other species (**Smith 1983**).

2.3.2. Description and Significance: Phosphorus

Phosphorus predominately occurs in natural freshwater areas as organically bound phosphate, within aquatic biota, or adsorbed to particles and dead organic matter (**Clesceri 1989; Wetzel 2001**); whereas, the dominant inorganic species, orthophosphate, accounts for about 10% of the total phosphorus in the system (**Clesceri 1989**). Orthophosphate is released by the breakdown of rock and soils and is then quickly used by aquatic biota, particularly bacteria and algae, and incorporated as organic phosphate (**Kenney, et al. 2002; Newbold 1992**). Phosphorus can be released from biota by excretion and by the decaying of matter. Several other factors can influence the partitioning of phosphorus in aquatic systems. In oxygen-rich headwater streams of the LSJR, phosphorus may be bound to mobile particulate material; however, in the lakes and slower flowing freshwater parts of the river, phosphorus settles in sediments (**Brenner, et al. 2001**). Many factors, such as wind, turbulence, DO, water hardness and alkalinity, sulfide concentration, salinity, and benthic (bottom-dwelling) organisms may potentially re-mobilize phosphorus into the water column (**Boström, et al. 1988; Boström, et al. 1982; Lamers, et al. 1998; Smolders, et al. 2006; Wetzel 1999**). When reaching the mouth of the river, sulfur may release phosphorus bound to sediments, thus making it potentially available to aquatic organisms (**Lamers, et al. 1998; Smolders, et al. 2006**). This occurs more commonly in anoxic areas where bacteria reduces sulfate to sulfide as they decompose organic matter (**Lamers, et al. 1998; Smolders, et al. 2006**).

Humans add to the naturally occurring phosphorus in aquatic systems. In central Florida, phosphorus is mined quite extensively, and is used in fertilizers, commercial cleaners and detergents, animal feeds, and in water treatment, among other purposes. Runoff can result in the addition of phosphorus into local waterways (**Clesceri 1989; Wright and Nebel 2008**). In the past, phosphorus was also often used in laundry detergents. Orthophosphate generally averages 0.010 mg/L whereas total dissolved phosphorus averages about 0.025 mg/L in unpolluted rivers worldwide (**Meybeck 1982**). Orthophosphate concentrations in rivers can increase substantially following a rainwater event to as high as 0.050-0.100 mg/L from agricultural runoff and over 1.0 mg/L from municipal sewage sources (**Meybeck 1982; Meybeck 1993**).

The drainage basin for the river consists of agricultural lands, golf courses, and urban areas, all of which add to the phosphorus loading in the river. Those inputs, plus effluents from municipal wastewater treatment plants and other point sources may contribute to eutrophic conditions in the LSJR.

2.3.3. Management of Nutrients

Nutrient excesses in the LSJR have led to algal overabundance and low dissolved oxygen levels throughout the river. To address the problems, a final TMDL report was drafted in 2008 by the DEP to reduce nutrient inputs into the LSJR so that algal blooms are reduced in the freshwater regions and healthy levels of dissolved oxygen are maintained in the marine portions of the river. A TMDL is a scientific determination of the maximum amount of a given pollutant (i.e. nutrients) that a surface water body can assimilate and still meet the water quality standards that protect human health and aquatic life (**Magley and Joyner 2008**; see Section 1). The nutrient TMDL indicates how much nutrients need to be reduced to meet water quality standards in the LSJR. Subsequent Basin Management Action Plans establish restoration strategies required to achieve the water quality standards. Government agencies are working with municipal and industrial wastewater treatment facilities and NPDES permitted facilities to reduce nutrient loadings from permitted discharges. Also, nutrient-rich waters coming from standard secondary water treatment plants may be recycled. These recycled waters can and have recently been used as a means for irrigation when nontoxic. This practice has been recently utilized in Clay County, within the LSJRB, as well as other areas of the U.S, mostly for irrigation of urban open spaces like parks, residential lawns and golf courses. A similar practice has been used in agriculture.

Local utilities and government agencies have worked to reduce nutrient discharges since 2000 including a large public outreach campaign to reduce fertilizer use in residential landscapes. Individual homeowners may also introduce excess nutrients into the LSJR through failing septic tanks; therefore the replacement of these septic tanks is one of the actions designated to achieve the proposed TMDL. Government agencies have been working with farming and silviculture operations to implement best management practices to reduce and treat runoff of nutrients. The reduction and treatment of urban stormwater runoff by municipal stormwater programs, improvement of development design and construction by commercial developers and homebuilders, and restoration projects by federal, regional, and state agencies may all influence the attainment of projected future goals of the TMDL program. These methods among others have been included in the DEP Nutrient TMDL (**Magley and Joyner 2008**) and have widespread implications in reducing inputs of nutrients into the St. Johns River, provided government agencies, stakeholders, and the general public can meet this goal. Progress towards meeting those goals for the mainstem has most recently been reviewed in the 2013 LSJR Mainstem Basin Management Action Plan progress report (**DEP 2014d**).

In August 2013, the FDEP submitted a plan to EPA to implement numeric nutrient standards in Florida's waters. The FDEP discussed how it developed numeric interpretations of existing State narrative criteria (**DEP 2013m**). For streams without site-specific interpretations required by TMDL stipulations, numeric thresholds and biological benchmarks were developed to assess nutrient status. The nutrient thresholds for peninsular Florida, based on analysis of reference streams, were 0.12 mg TP/L and 1.54 mg TN/L. These values are not to be exceeded more than once in a three year period and are based on annual geometric means. Annual geometric means are similar to medians in that outliers (i.e., extremely high or extremely low values) influence the result less than they influence arithmetic means. Extensive biological assessment accompanies the numeric thresholds.

In August 2013, the FDEP and the Division of Environmental Assessment and Restoration reported to the Governor and Florida legislature on the status of efforts to establish numeric nutrient standards from narrative criteria (**DEP 2013l**). In this document, the site-specific numeric standards for the LSJR, including marine tributaries, were expressed as TMDL loading per year, 1,376,855 kg TN/year and 412,720 kg TP/year. The numeric interpretation for chlorophyll-a is that the long-term annual averages will not exceed 5.4 μg/L. In late 2014, the FDEP Environmental Regulation Commission approved slightly different numeric criteria for the LSJR that await approval by EPA (**DEP 2015a**).

2.3.4. Data Analysis

Because of the variability in the characteristics of the river extending from the mouth to the freshwater lakes, it is useful to examine the differences in nutrient profiles in different river regions. The section we refer to as the marine/estuarine reach spans from the mouth at WBID 2213A to WBID 2213G which contains Doctors Lake (Figure 2.1). The freshwater region extends from WBID 2213H upstream to WBID 2213N at the confluence of the Ocklawaha River.

The nutrients assessed include total nitrogen (TN), total phosphorus (TP), nitrate plus nitrite (NO3-NO2), and orthophosphate (OP). The TN and TP parameters reflect total loading of nutrients into the system including different forms that are readily transformed and those that decay slowly. The sums of the dissolved and particle-bound forms are included in the TN and TP assessments. Orthophosphate, nitrate-nitrite, and ammonia are inorganic nutrients that are considered reactive because they can be taken up rapidly by biota and readily undergo chemical reactions in the environment. Only the dissolved forms of reactive nutrients are assessed and discussed. Chlorophyll-a is an indirect measure of biological responses to nutrient enrichment and is included in some discussions below. More detail about chlorophyll-a and its relationship to phytoplankton growth is provided in the following section on harmful algal blooms.

In this report, the numeric standards for nutrients in peninsular Florida (**DEP 2013m**), described above in Section 2.3.3, are compared to LSJR data to generally assess the status of the LSJR. However, the water body is not regulated under those standards; numeric criteria consist of total nutrient loading rates that cannot be compared to water concentrations. While nitrate is regulated for springs and drinking water, neither application is appropriate for the LSJR. There is no Florida orthophosphate criterion.

In the following analyses, the current status and time trends of the four nutrients are examined in different ways. Data are displayed in annual box and whisker plots, which show the distribution of the high and low concentrations each year. These plots consist of a five number summary including: a minimum value, value at the first quartile, the median value, the value at the third quartile, and the maximum value. The size of the box is a measure of the spread of the data with the minimum and maximum values indicated by the whiskers. The median value is the value of the data that splits the data in half and is indicated by the horizontal blue line in the center of the boxes. The peninsular Florida numeric nutrient thresholds for streams, described above, are overlaid on the charts as a general reference point to assess the status of the LSJR.

Trends over time in annual average concentrations are identified by using the Spearman Rank 1-tailed test at $p< 0.05$ (trend p values given in Appendix 2.3.6).

All data were obtained from the FDEP STORET. STORET is a statewide computerized environmental data system containing water quality, biological, and physical data. Total phosphorus was measured in surface waters using EPA methods 365.4 and 365.1. Total Kjeldahl nitrogen (organic nitrogen plus ammonia), total ammonia, and nitrate plus nitrite were measured using EPA methods 351.2, 350.1 or 4500-G, and 353.2, respectively. Total nitrogen was calculated from the sum of the Kjeldahl nitrogen and nitrate-nitrites in each sample. Data for the entire basin and tributaries were collected from FDEP STORET and culled for applicability to this study. Only stations in the mainstem or near the mainstem in major tributaries such as the Ortega River and Julington Creek were included. Data were reviewed for quality and data points were discarded when samples appeared analytically compromised (contaminated blanks, poor recovery, poor replication, etc.) or were missing important information. All samples with qualifier codes K, L, O, V, Y or ?, which indicate different data quality issues, were eliminated. If a value below the method detection limit (MDL) was reported, it was used even if flagged. One-half the MDL was used for samples reported as "nondetect". In a small number of cases, the MDL was estimated by determining the MDL reported most frequently for other samples during the same year.

The 2014 data set is included in the analysis but limited in number. At the time the data were compiled from FL STORET in January 2015 for this report, nutrient data ended in May 2014 and these were mainly in the marine/estuarine section. Few or no 2014 data were available for the freshwater section at the time of data compilation. The number of data points in each WBID and year are given in Appendix 2.3.6.

2.3.5. General Characteristics

Nutrient profiles vary with the region of the river and depend on proximity to the mouth, rainfall, local sources, and upstream and tributary sources, as well as biological activity (Figure 2.6). The dilution of river water with lower-nutrient ocean water is evident for most nutrients because annual average concentrations sharply decrease as the river reaches the mouth in WBIDs 2213A-2213C. In most years, both forms of phosphorus and nitrate-nitrite concentrations increase as the fresh water moves downstream to estuarine areas, where it becomes diluted by ocean water. By contrast, TN and pheophytin-corrected chlorophyll-a gradually decrease as the river moves from freshwater to estuarine conditions (Figure 2.6). As a consequence of the different ratios of nitrogen to phosphorus, the downstream, saltier section is generally more susceptible to nitrogen pollution, and the upstream, more riverine section is more susceptible to phosphorus pollution.

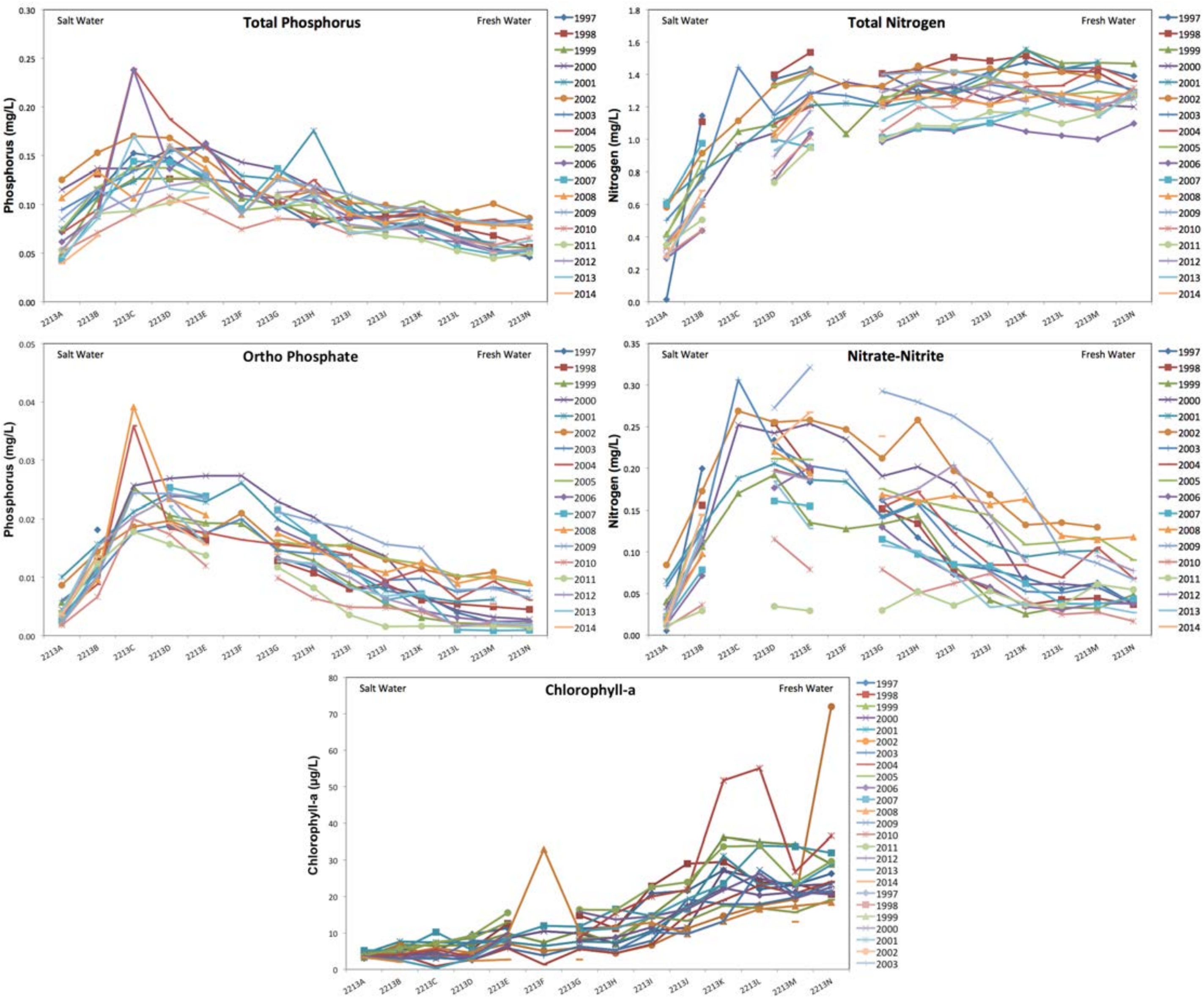


Figure 2.6 Annual averages of nutrients and chlorophyll-a in the LSJR by WBID. WBIDs 2213A-G are marine/estuarine waters and WBIDs H-N are freshwater.

2.3.6. *Current Status and Trends: Total Nitrogen*

The median mainstem total nitrogen concentrations have been below the TN water quality reference concentration of 1.54 mg N/L in both marine/estuarine and freshwater sections of the river since 1998. The TN median in the marine/estuarine section was 1.09 mg N/L in 2014. As noted above (Section 2.3.4) no data were available for the freshwater section for 2014 at the time the data were compiled. However, in 2013 the median for the freshwater section was 1.14 (Figure 2.7), also well below the water quality reference concentration. See Appendix 2.3.6 for annual maxima, medians, averages and geometric means.

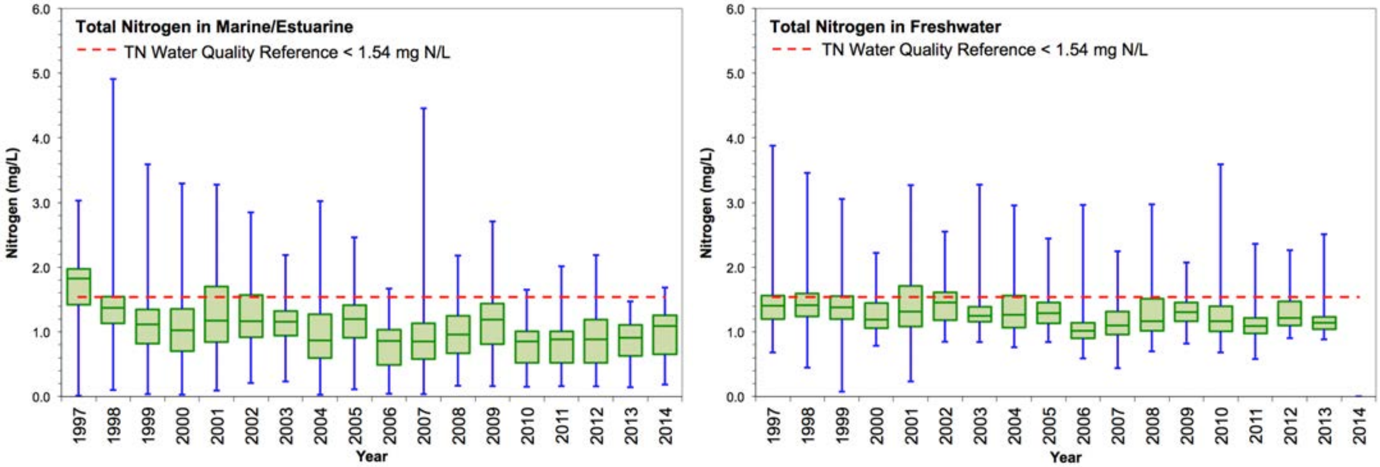


Figure 2.7 Yearly total nitrogen concentrations from 1997 to 2014 in the Lower St. Johns River mainstem for marine/estuarine and freshwater regions. Data are presented as a box-and-whiskers plot with the green boxes indicating the median±25% (middle 50% of the data) and horizontal lines indicating the median values. Blue whiskers indicate the minimum and maximum values in the data set. Note that no data were available for freshwater in 2014.

Annual average concentrations of total nitrogen have declined gradually but significantly in both marine/estuarine and in freshwater parts of the lower basin (Figure 2.8). Average total nitrogen levels in the marine/estuarine river regions declined by 31% since 1997, while freshwater reductions from 1997 to 2013 were more modest at 15%. Reductions in the marine reach total nitrogen concentrations have been attributed in part to increasing input from low-concentration marine water, but significant reductions in loading of nitrogen are also likely to be responsible for the decline (**DEP 2013c**). The TN annual maxima have also declined since 1997 in both the marine/estuarine section and the freshwater section of the river. See Appendix 2.3.6 for additional trend information.

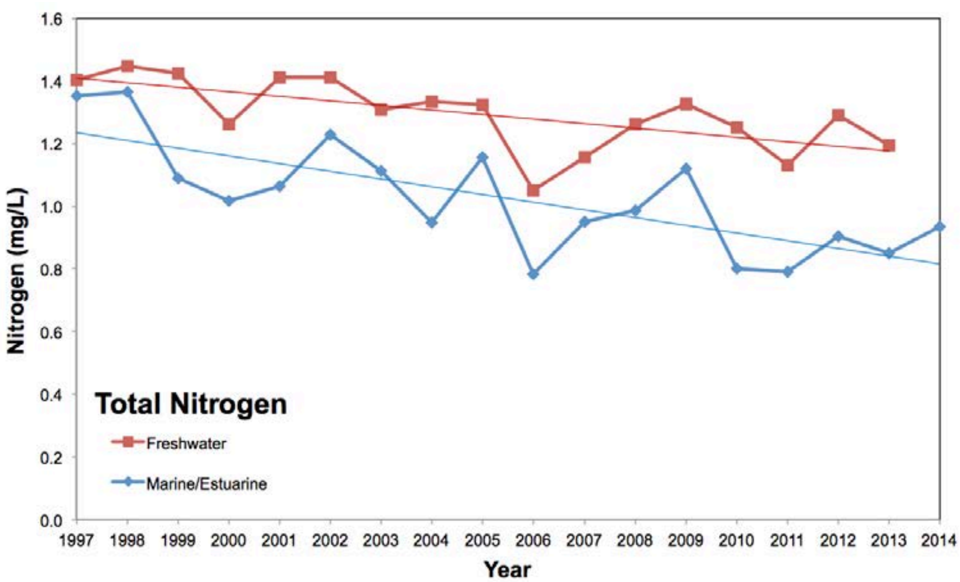


Figure 2.8 Average annual total nitrogen concentrations in the marine/estuarine reach (WBID 2213A upstream to WBID 2213G) and freshwater section (WBID 2213H upstream to WBID 2213N) of the LSJR mainstem. Trends indicated by a trend line were statistically significant using Spearman Rank at p<0.05. See Appendix 2.3.6 for additional trend information. Note that no data were available for freshwater in 2014.

Relatively elevated levels of nitrogen have been frequently observed in several tributaries (see below); as well as specific locations in the mainstem of the LSJR, such as the Main St. Bridge, which receives a substantial upstream contribution, city storm drainage inputs and power plant effluent, as well as atmospheric deposition, making it difficult to identify a predominant source.

2.3.7. *Current Status and Trends: Total Phosphorus*

In 2014, the median total phosphorus concentrations in both the marine/estuarine and the freshwater sections of the mainstem were below the TP reference concentration of 0.12 mg P/L. The medians for both the marine/estuarine and the freshwater regions were 0.08 mg P/L in 2014 (Figure 2.9). As noted above (Section 2.3.4), the 2014 TP data were limited in number at the time of STORET data retrieval, particularly in the freshwater section. In general, the mainstem has lower phosphorus concentrations than several of the creeks and tributaries (see Section 2.8) that may act as phosphorus sources to the mainstem.

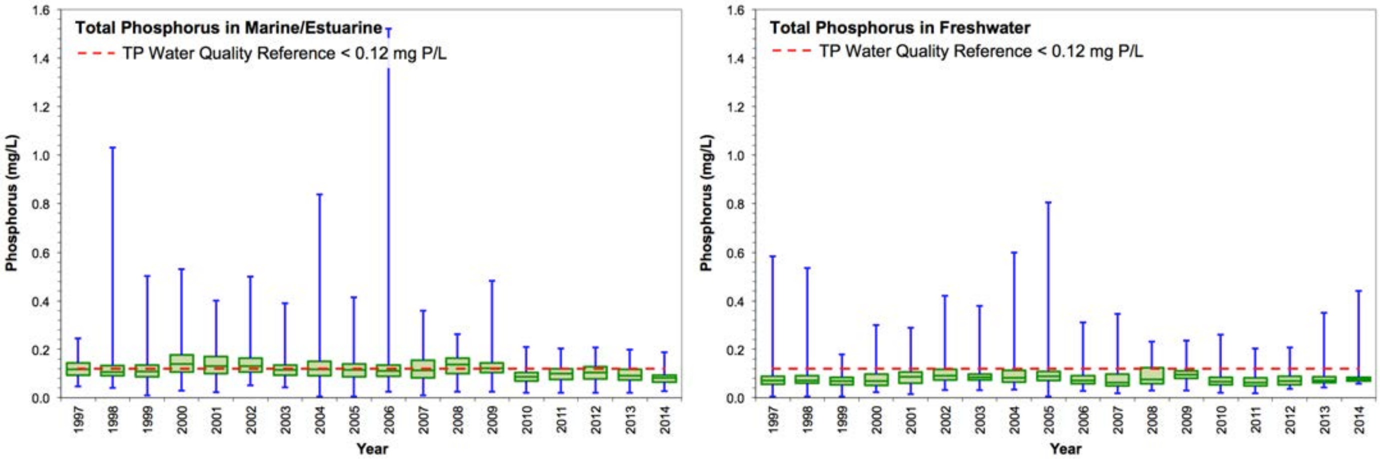


Figure 2.9 Yearly total phosphorus concentrations from 19978 to 2014 in the Lower St. Johns River mainstem for marine/estuarine and freshwater regions. Data are presented as a box-and-whiskers plot with the green boxes indicating the median±25% (middle 50% of the data) and horizontal lines indicating the median values. Blue whiskers indicate the minimum and maximum values in the data set.

The annual average concentration of total phosphate has declined significantly in the marine/estuarine section, but freshwater concentrations have not (Figure 2.10). Average total phosphorus concentrations in the marine/estuarine WBIDS were 33% lower in 2014 compared to 1997, whereas freshwater WBID samples were 45% higher in 2014, though no overall upward trend was detected for the latter.

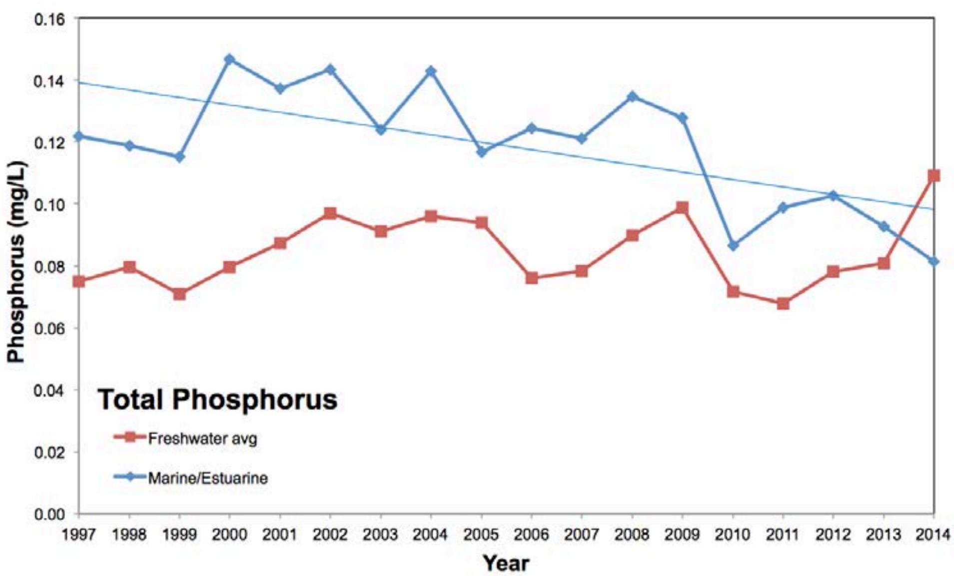


Figure 2.10 Average annual total phosphorus concentrations in the marine/estuarine reach (WBID 2213A upstream to WBID 2213G) and freshwater section (WBID 2213H upstream to WBID 2213N) of the LSJR mainstem. Trends indicated by a trend line were statistically significant using Spearman Rank at p<0.05. See Appendix 2.3.6 for additional trend information.

Slight seasonal increases in phosphorus concentration in the LSJR are generally observed in summer months (Figure 2.11). Fertilizers containing phosphorus are used on crops primarily during the winter; however, increased stormwater runoff during the summer adds phosphorus from soil, resulting in a continuous input into the LSJR.

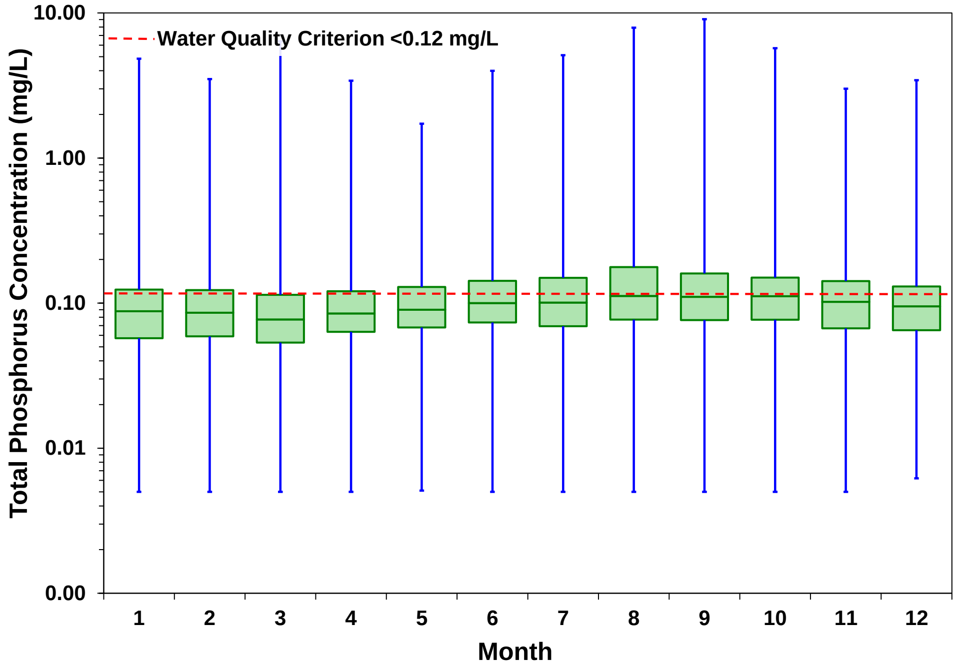


Figure 2.11 Monthly total phosphorus concentrations from 1998 to 2011 in the Lower St. Johns River. Data are presented as a box-and-whiskers plot with the green boxes indicating the median ±25% (middle 50% of the data) and horizontal lines indicating median values. Blue whiskers indicate the minimum and maximum values in the data set.

2.3.8. Current Status and Trends: Nitrate and Phosphate

The reactive inorganic nutrients nitrate-nitrite and orthophosphate are readily taken up by various organisms and released back into the environment. Concentrations of the two nutrients vary widely with environmental conditions such as rainfall and phytoplankton growth. The median concentration of nitrate-nitrite in the marine/estuarine sections in 2014 (0.22 mg N/L) was substantially higher than the median freshwater sections in 2013 (0.02 mg N/L) (Figure 2.12). As noted above (Section 2.3.4), 2014 data were limited in number at the time of the STORET data retrieval for this report and no nitrate data were available for 2014 for the freshwater region.

Along with nitrate, orthophosphate tends to be higher in the marine/estuarine section than in the freshwater section (Fig 2.13, 2.14). An exception is 2014 but there was just a single data point for orthophosphate in the freshwater section of the river so these results are inconclusive. The median orthophosphate concentration in 2013 was more than twice that in 1997 in the freshwater regions of the river, but was 11% lower in the saltier regions during that time.

Despite the variability over time in the concentrations of the reactive inorganic nutrients, there was still a statistically meaningful downward trend in nitrate and orthophosphate concentrations in the marine/estuarine section (Figure 2.14). No trends in freshwater nitrate and orthophosphate concentrations were evident. An interesting feature of both time series is the low concentrations in 2010-2011 corresponding to times of intense algal blooms. Significant phytoplankton growth and die-off contribute to the fluctuations as nutrients are consumed and released.

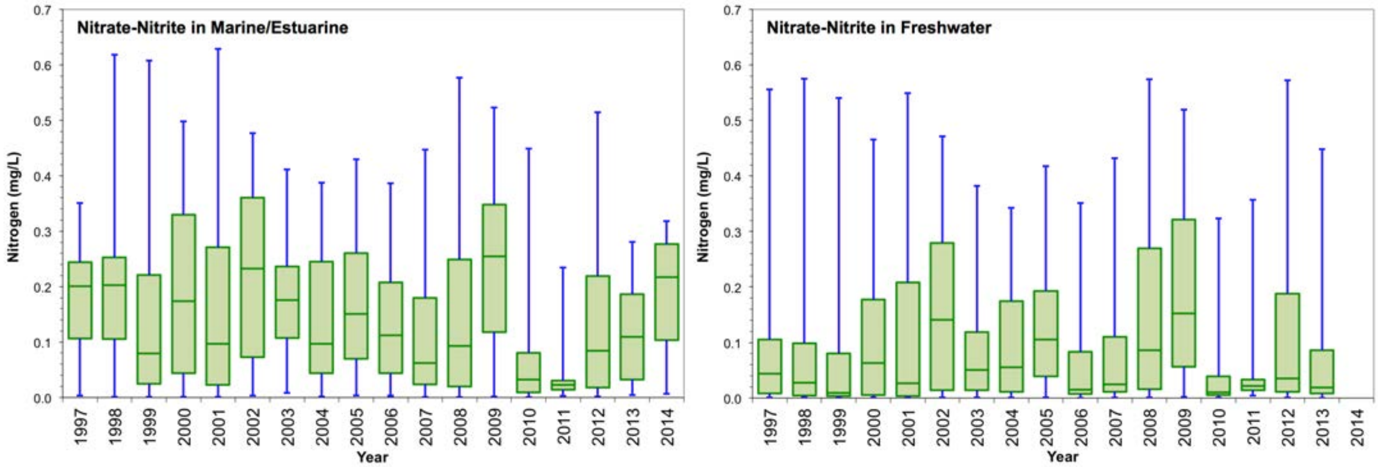


Figure 2.12 Yearly nitrate and nitrite concentrations from 1997 to 2014 in the Lower St. Johns River mainstem for marine/estuarine and freshwater regions. Data are presented as a box-and-whiskers plot with the green boxes indicating the median±25% (middle 50% of the data) and horizontal lines indicating the median values. Blue whiskers indicate the minimum and maximum values in the data set. Note that no data were available for freshwater in 2014.

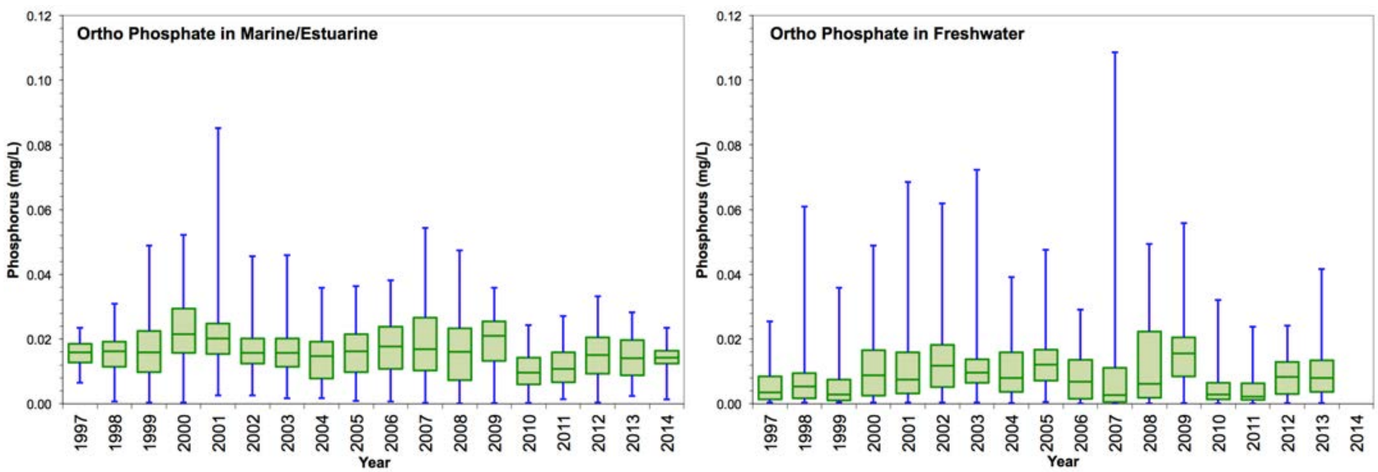


Figure 2.13 Yearly orthophosphate concentrations from 1997 to 2014 in the Lower St. Johns River mainstem for marine/estuarine and freshwater regions. Data are presented as a box-and-whiskers plot with the green boxes indicating the median±25% (middle 50% of the data) and horizontal lines indicating the median values. Blue whiskers indicate the minimum and maximum values in the data set. Note that only one data point was available for freshwater in 2014.

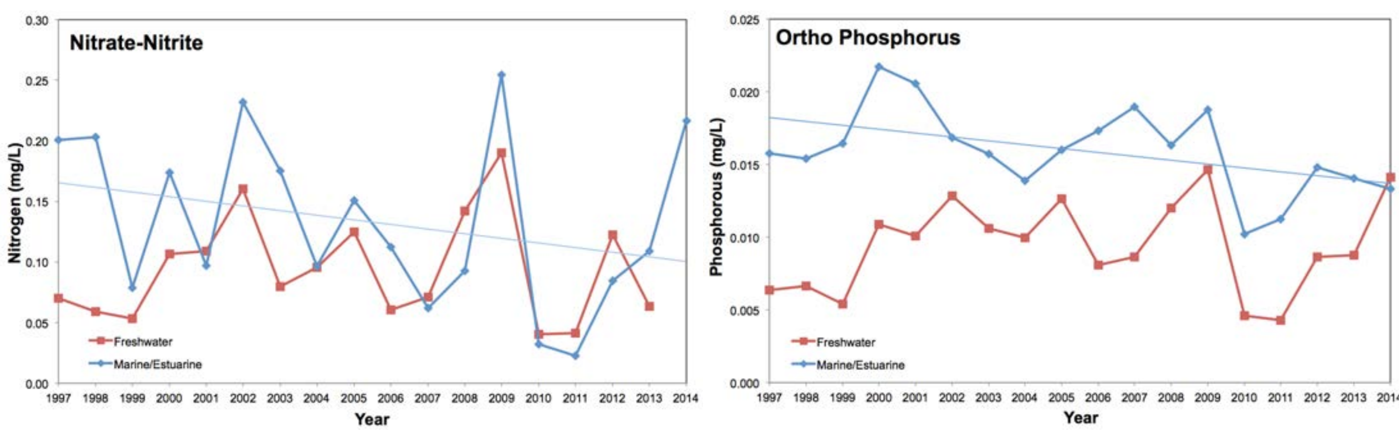


Figure 2.14 Average annual nitrate-nitrite and orthophosphate concentrations in the marine/estuarine reach (WBID 2213A upstream to WBID 2213G) and freshwater section (WBID 2213H upstream to WBID 2213N) of the LSJR mainstem. Trends indicated by a trend line were statistically significant using Spearman Rank at p<0.05. See Appendix 2.3.6 for additional trend information. Note that no nitrate data were available for freshwater in 2014 and only one orthophosphate data point was available.

There is a seasonal trend in the levels of nitrate and nitrite, with the highest concentrations occurring in the winter (Figure 2.15). This may be the result of limited uptake of nitrate for phytoplankton growth in winter months.

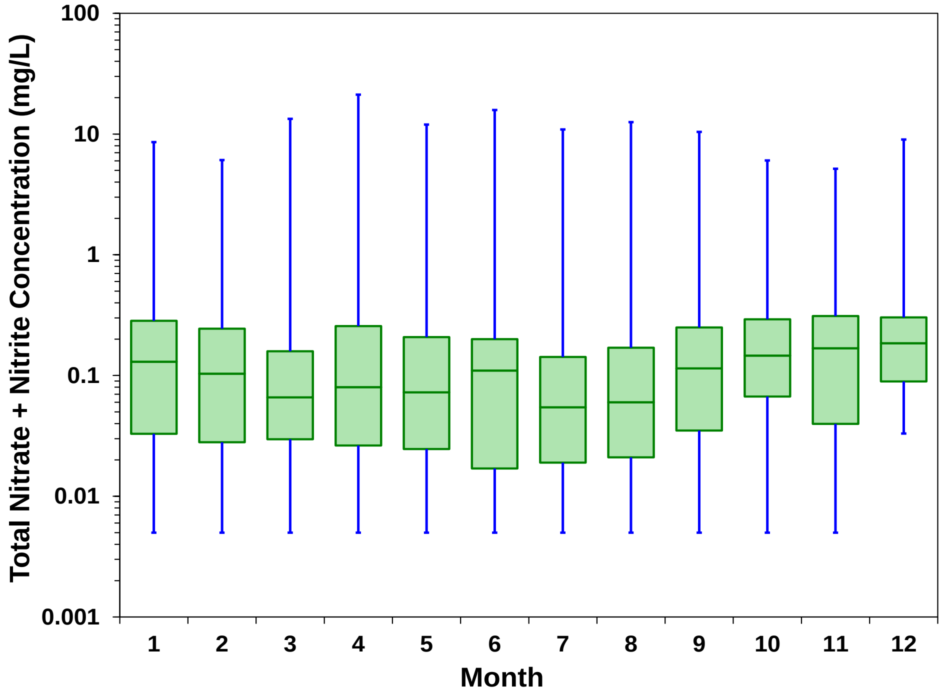


Figure 2.15 Monthly nitrogen concentrations, as nitrate + nitrite, from 1998 to 2011 in the Lower SJR. All data are presented as a box-and-whiskers plot with the green boxes indicating the median ±25% (middle 50% of the data) and horizontal lines indicate the median values. Blue whiskers indicate the minimum and maximum values in the data set.

2.3.9. *Summary and Outlook*

Average annual total nitrogen concentrations are slowly declining throughout the river since 1997 but total phosphorus levels are declining only in the marine/estuarine section. There are wide fluctuations of these and other nutrients due to phytoplankton growth and die-off as well as weather conditions. Reduced nutrient loading may be lowering concentrations of some forms of nutrients in the mainstem, but an accompanying reduction in algal growth, as indicated by average annual chlorophyll-a levels, has not yet been demonstrated (Section 2.4). For these reasons, the overall **STATUS** of nutrients **is *unsatisfactory***. The **TREND** for nitrogen is ***improving***, the **TREND** for phosphorus is ***improving***.

The complex ecology of the LSJR and its highly variable characteristics and weather patterns make it difficult to assess its overall status. As a result, assessments can differ when different methods of analysis are used. It is reported in the 2013 LSJR BMAP progress report that total nitrogen is decreasing at benchmark sites in marine and freshwater areas of the river (**DEP 2014d**). Total phosphorus is unchanged at the freshwater site but could be increasing at the marine site. The next few years will be critical in definitively determining when the considerable effort and expenditures to reduce nutrients in the LSJR have been successful. Robust data sets are particularly critical for assessing trends.

Numerous projects have been carried out by multiple counties and agencies in the last several years to reduce nonpoint sources of nutrients from stormwater runoff, agricultural runoff, landscape fertilizer and septic tanks, as well as point sources such as wastewater treatment plants. Projects include wastewater treatment plant upgrades, reclaimed water projects, general drainage improvement, septic tank phase-outs, and the construction of regional stormwater treatment facilities. These efforts are detailed in the 2013 LSJR Mainstem Basin Management Action Plan progress report (**DEP 2014d**). In addition, nongovernmental NPDES permit holders have also reduced the discharge of nutrients in their effluents to meet TMDL load reduction allocations. In an interesting, cost-effective restoration project in Lake Apopka, the SJRWMD is reducing the mobilization of phosphorus from sediments by harvesting gizzard shad, which disturb the sediments and release the phosphorus for uptake by algae (**DEP 2014d**). As a consequence of all of these efforts, the lower basin stakeholders have made substantial progress in meeting their targeted nutrient load reductions required by the LSJR TMDL limits, a very positive development for the river.

Whether load reductions and numeric criteria have achieved a real environmental benefit at this point is an important question. To accurately answer it, reliable and consistent data is essential. There is a very clear need for continued and increased monitoring to assess the effectiveness of the nutrient TMDLs that have been implemented for the LSJR mainstem. Responses to TMDL efforts of other water bodies in the entire St. Johns River basin, particularly upstream and tributaries, also need to be monitored if benefits are to be accurately assessed. It is critical to maintain adequate monitoring capacity for nutrients, chlorophyll-a and other water quality parameters in the LSJR mainstem so that information that is essential for effective management is available.

2.4. Algal Blooms

2.4.1. Description and Significance

Healthy rivers and lakes abound with phytoplankton (microscopic plants) that photosynthesize and serve as the base of the food chain. Cyanobacteria (also called blue-green algae) are one type of phytoplankton that exist in healthy ecosystems. Some species thrive in salt water, some in fresh water, and some tolerate wide ranges of salinity. Under the right conditions of nutrients, light, salinity and river flow, these organisms can propagate rapidly and result in very high concentrations of the algae, creating what is called a “bloom” (Figure 2.16). These blooms can have significant impacts on the local ecology of a river.

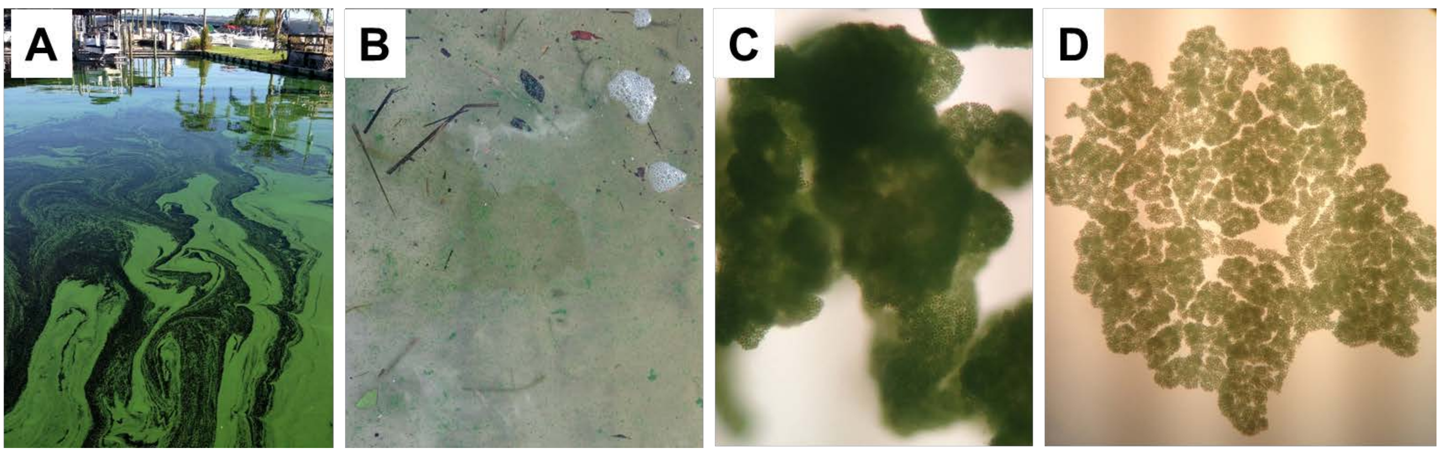


Figure 2.16 Microcystis-dominated blooms at Doctors Lake (A) and Lions Club Park (B) exhibiting slick-like and clump-like manifestations in October and September 2013, respectively. Microscope images of Microcystis colonies at low (C) and high (D) magnifications. Photos by Rhea Derke.

Algal blooms are often described as nuisances because of the odor and unsightliness of algal scum and the green water that often accompanies them. However, the potential impacts go well beyond being a nuisance. Blooms, in addition to being clearly visible events, often induce high oxygen production during the daylight hours, followed at night by very low oxygen levels. In typical diurnal DO cycles (over a period of 24 hours) there is an increase of DO during the day because of photosynthesis by the phytoplankton, and decrease at night due to cyanobacterial respiration and due to the decay of the bloom biomass (Figure 2.17) (**Steidinger, et al. 1999**). Other effects occur when blooms are so dense that sunlight cannot reach the native submerged aquatic vegetation, reducing its ability to photosynthesize and grow. As a consequence, survival of juvenile fish and other aquatic organisms may become threatened by low oxygen and reduced food and habitat caused by algal blooms.

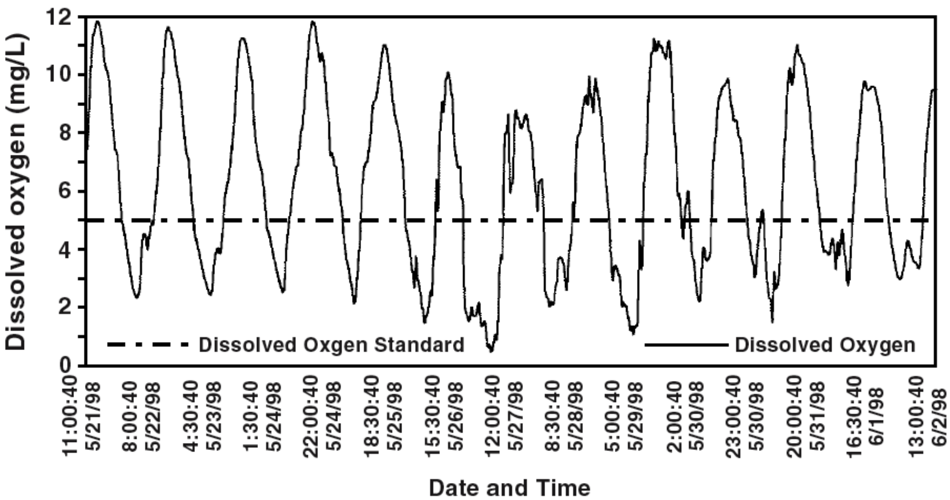


*Figure 2.17 Diurnal cycles of dissolved oxygen during Doctors Lake HAB event in 1998 from **Steidinger, et al. 1999** page 24.*

Some cyanobacteria species also produce toxins that can reach high levels in a bloom, potentially creating public health problems and causing widespread deaths of fish and other aquatic organisms. These incidents are known as Harmful Algal Blooms (HABs). Cyanobacteria produce three broad classes of toxins known as hepatotoxins, neurotoxins, and dermatotoxins that affect the liver, nerves, and skin respectively (**Burns Jr 2008; Sivonen and Jones 1999; Williams, et al. 2007**). In addition to toxic effects, general irritation can occur upon contact (**Chorus and Bartram 1999**). Swimmers and anglers have complained of rashes after coming into contact with blooms (**Steidinger, et al. 1973**). The World Health Organization (WHO) has set a drinking water "provisional consumption" limit of 1 $\mu g/L$ for one type of cyanotoxin, microcystin-LR, the toxin produced by several types of cyanobacteria, including *Microcystis* species (**Chorus and Bartram 1999**). The safety of recreational waters to swimmers, sailboard riders and water-skiers have been categorized as mild, moderate, or high risk, depending on cyanobacteria quantities and species (**Chorus and Bartram 1999**). For recreational water, the WHO considers 20 μg/L microcystin-LR to have a moderate probability of adverse health effects for a 132 pound adult that ingests 3.4 oz. of contaminated water. A 30 pound child would need to ingest less than 1 ounce for the same risk (**Chorus and Bartram 1999**). As cyanobacteria concentrations increase, so does the potential for people to ingest toxins at levels that can cause adverse effects. The presence of scums produced by some species such as *Microcystis* and *Anabaena* is particularly hazardous. They contain high levels of toxin so it is important for the public and their pets to avoid exposure to them (**Chorus and Bartram 1999**). Four summary references on HAB by **Steidinger, et al. 1999**, **Burns Jr 2008**, **Williams, et al. 2007**, and **Abbott, et al. 2009** are recommended reading on this subject.

The St. Johns River and particularly its tributaries are impacted by excess nutrients in runoff and wastewater (see nutrient section above). Nutrients, including nitrogen- and phosphorus-based chemicals contained in garden, lawn, and agricultural fertilizer, are common causes of impaired waters in the LSJR and are a crucial contributor to freshwater algal blooms. High levels of nutrients lead to phytoplankton growth and eutrophication. Excess nutrients cause the ecosystem to become unbalanced and increase organic matter loading to the system (**NRC 2000**). When nutrient levels are high and other appropriate conditions exist, the possibility of harmful algal blooms increases. Growth rates of cyanobacteria and species distribution in an ecosystem are highly dependent upon light, temperature, and salinity. As a consequence, proximity to the mouth of the river, temperature fluctuations, color of the water, and the presence of other phytoplankton all determine whether an algal bloom will occur and which species will predominate. Rainfall also influences HABs; periods of low flow during drought increase the likelihood of algal blooms in the freshwater reach (**Phlips, et al. 2007**), while high flow and hurricane rain events increase the likelihood of less concentrated but more widespread blooms in the downstream, Jacksonville reach of the river (**Hendrickson 2013**).

Nutrients promoting algal blooms also come from leaking septic systems, livestock, industry and runoff during and after heavy rain events. However, interesting work by **Piehler, et al. 2009** indicates some types of cyanobacteria can themselves increase nitrogen in water bodies. During nitrogen fixation, a biological process, atmospheric nitrogen is taken up and used for growth by some species. The nitrogen is ultimately released into the water in forms that are more usable by biota that cannot use atmospheric nitrogen.

The question often arises about whether harmful algal blooms occurred historically and whether current blooms are a natural occurrence. Burns has this to say (**Burns Jr 2008**):

> *"Although there is little doubt that the phenomenon of cyanobacterial blooms predates human development in Florida, the recent acceleration in population growth and associated changes to surrounding landscapes has contributed to the increased frequency, duration, and intensity of cyanobacterial blooms and precipitated public concern over their possible harmful effects to aquatic ecosystems and human health. Toxic cyanobacterial blooms in Florida waters represent a major threat to water quality, ecosystem stability, surface drinking water supplies, and public health".*

Interestingly, algal blooms may have increased after successful eradication efforts to control the highly invasive water hyacinth in the 1970s and 1980s. In the past, hyacinth shaded much of the water column and limited algal growth. Reduction in the water hyacinth may have contributed to the change from a floating aquatic plant system to an algal-dominated system in the LSJR (**Hendrickson 2006; Hendrickson 2008; Moody 1970**).

2.4.2. Cyanobacteria in Florida and the LSJR

Anabaena circinalis and *Microcystis aeruginosa* (Figure 2.17) are two of the most widely distributed freshwater cyanobacteria species in Florida that generate HABs (**Abbott, et al. 2009; Steidinger, et al. 1999; Williams, et al. 2007**). Some of the other potentially toxic cyanobacteria that are known to bloom in Florida waters include *Cylindrospermopsis raciborskii* (reported as a possibly recent invasive species (**Chapman and Schelske 1997**)), *Anabaena flos-aquae, Aphanizomenon flos-aquae*, and *Lyngbya wollei* (**Abbott, et al. 2009; Burns Jr 2008; Steidinger, et al. 1999**). Extensive statewide sampling by Florida biologists in 1999-2000 showed that 88 out of 167 samples, representing 75 individual water bodies, were found to contain potentially toxic cyanobacteria (**Burns Jr 2008; Williams, et al. 2001**). Most bloom-forming cyanobacteria genera were distributed throughout the state, but water bodies such as Lake Okeechobee, the LSJR, the Caloosahatchee River, Lake George, Crescent Lake, Doctors Lake, and the St. Lucie River (among others) were water bodies that supported extensive cyanobacterial biomass. Seven genera of cyanobacteria were identified in the statewide samples, with *Microcystis* (43.1%), *Cylindrospermopsis* (39.5%), and *Anabaena* (28.7%) the most frequently observed, and in greatest concentration. (**Burns Jr 2008; Williams, et al. 2001**). In the same 1999-2000 survey, 55% of the samples in the LSJR basin contained the genus *Anabaena*, 53.9% contained *Cylindrospermopsis raciborskii*, and 47.6% contained the genus *Microcystis* (**Williams, et al. 2001**; **Burns Jr 2008**), though it should be noted that many other species reside in the LSJR.

More recently in 2005, major blooms in the LSJR affected areas north of Crescent City to Jacksonville and caused large spikes in cyanotoxins and fish die-offs. The primary species was *Microcystis aeruginosa* (**Williams, et al. 2007; Williams, et al. 2006**). In an unusual series of events in the LSJR in 2010, from mid-May through June of 2010, cyanobacteria blooms grew in great abundance in the freshwater reaches of the LSJR, beginning with blooms of *Aphanizomenon cf. flos-aquae*. *Aphanizomenon* is not unique to the LSJR, but until then it had never been the dominant species. With an increase in river salinity due to extended periods of reverse flow, the *Aphanizomenon* bloom decayed and was replaced by *Microcystis*, *Cylindrospermopsis*, *Anabaena*, and *Pseudoanabaena* (**FWC 2010**). Analyses for cyanotoxins, which are toxic chemicals produced by cyanobacteria, indicated large spikes of a microcystin in the river water in late May and June and elevated levels of *Cylindrospermopsis* in mid-July through September (**Hendrickson 2011**).

Other cyanobacteria identified in the LSJR in 2012 by the SJRWMD Field Observation team include *Anabaena spiroides Oscillatoria limosa*, in the Ocklawaha River in 2012, as well as *Planktolyngbya limnetica* and *Planktolyngbya tallingi* in Crescent Lake (**LSJR TAC 2012**).

Identification and quantitation of cyanobacteria and their toxins in the LSJR is difficult, expensive, and time-consuming, though in recent years, there has been an expansion of different methods and approaches (**Burns Jr 2008; Williams, et al. 2007**). The most consistent and complete data that reflects phytoplankton growth over many years are measurements for chlorophyll-a. Chlorophyll-*a* is a light-harvesting pigment used by photosynthesizing organisms. Elevated phytoplankton concentrations, including cyanobacteria, are accompanied by elevated chlorophyll-a concentrations so it is often used as an indicator for HABs.

2.4.3. Chlorophyll-a Thresholds and Data Analysis

Chlorophyll-*a* values are used to determine relative phytoplankton abundance. Each water body is unique with respect to flow, shape, and water chemistry, all which affect phytoplankton growth and therefore also chlorophyll-a levels (**DEP**

2013m). Because salinity is critical factor in cyanobacteria growth, it is useful to examine chlorophyll-a in different river regions. The marine/estuarine reach discussed in this report extends from the mouth at WBID 2213A to WBID 2213G, which contains Doctors Lake (Figure 2.1). The freshwater region extends from WBID 2213H upstream to WBID 2213N at the confluence of the Ocklawaha River and is where cyanobacteria thrive.

Streams with chlorophyll-a concentrations that are below 3.2 μg/L are biologically healthy, however, some types of streams are stable and healthy at 20 μg chlorophyll-a/L, or higher. Therefore, a number of FDEP chlorophyll-a impairment thresholds exist for Florida waterways ranging from general criteria to site-specific criteria. The DEP considers 40 μg chlorophyll-a/L as the threshold for a nuisance cyanobacterial bloom (**DEP 2014d**). Generally, 20 μg chlorophyll-a/L is the impairment threshold for Florida streams, based on annual geometric means (**DEP 2013m**). Annual geometric means are generally similar to medians in that outliers (i.e., extremely high or extremely low values) influence the result less than they influence arithmetic means. The impairment threshold for estuaries and open coastal waters is 11 μg chlorophyll-a/L (annual geometric mean) (**DEP 2013m**) However, the marine/estuarine reach of the LSJR has an even lower site-specific chlorophyll-a criterion of 5.4 μg/L for long-term annual averages (**DEP 2013l**). Thus, 5.4 μg/L is the threshold criterion we utilize in this report for the marine/estuarine reach, and 20 μg/L is the threshold we use for the freshwater portion.

In the following analyses, the current status and time trends of chlorophyll-a are examined in different ways. Data are displayed as annual averages (Figure 2.18) in order to compare to the threshold values (5.4 μg/L and 20 μg/L) as well as annual box-and-whisker plots (Figure 2.19; see figure legend for explanation of plot) which give a better representation of the spread of the data. It should be noted that we use the threshold value to generally assess the status of the LSJR, not to determine whether the LSJR is in compliance with the criterion since long-term averages are not calculated.

Trends over time in annual average concentrations are identified by using the Spearman Rank 1-tailed test at $p < 0.05$ (trend p values given in Appendix 2.3.6).

All data were obtained from the FDEP STORET. STORET is the statewide environmental data system containing water quality, biological, and physical data. Method 10200-G was used to analyze chlorophyll-a that was corrected for pheophytin, which is a form of degraded chlorophyll. Only stations in the mainstem or near the mainstem in major tributaries such as the Ortega River and Julington Creek were included. Data were reviewed for quality and data points were discarded when samples appeared analytically compromised (contaminated blanks, poor recovery, poor replication, etc.) or were missing important information. All samples with qualifier codes K, L, O, V, Y or ?, which indicate different data quality issues, were eliminated. If a value below the method detection limit (MDL) was reported, it was used even if flagged. One-half the MDL was used for samples reported as "nondetect". In a small number of cases, the MDL was estimated by determining the MDL reported most frequently for other samples during the same year.

2.4.4. Current Status and Trends

The freshwater regions have shown consistently higher concentrations of chlorophyll-a compared to the marine/estuarine regions (Figure 2.18). This is expected since the phytoplankton that cause harmful algal blooms in the St. Johns River are freshwater species. Using these annual averages, the freshwater portion had 2-7 times more chlorophyll-a than the marine/estuarine region each year (Figure 2.18). Furthermore, 6 of the 18 freshwater chlorophyll-a annual averages were above the general 20 μg/L value for freshwater, and 14 of the 18 marine/estuarine chlorophyll-a annual averages were above the 5.4 μg/L site-specific impairment threshold.

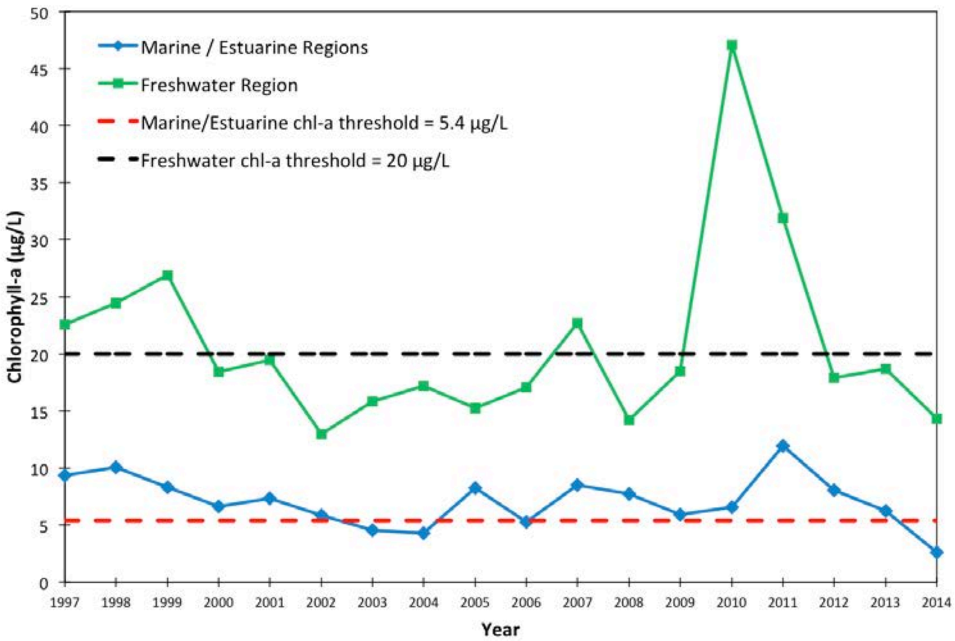


Figure 2.18 Average annual chlorophyll-a concentrations in the marine/estuarine reach (WBID 2213A upstream to WBID 2213G) and freshwater section (WBID 2213H upstream to WBID 2213N) of the LSJR mainstem. No trends were statistically significant using Spearman Rank at p<0.05. See Appendix 2.3.6 for additional trend information. The dashed lines represent the chlorophyll-a thresholds.

These data from 1997-2014 show no statistically significant trend upward or downward in average annual chlorophyll-a concentrations in the river (Figure 2.18). There was a notable spike in 2010 in the freshwater section when massive outbreaks of several species of cyanobacteria occurred. During that year, 80% of the samples in the freshwater WBIDS had chlorophyll-a levels greater than 20 µg/L and 50% had levels greater than 40 µg/L, concentrations suggesting significant ecological impact. The marine/estuarine portion had 47%, 14%, and less than 1% of the samples above 5.4 µg/L, 11 µg/L, and 40 µg/L chlorophyll-a respectively, during 2010. Thus, a significant number of samples in both the freshwater and marine sections of the LSJR exhibited elevated chlorophyll-a levels.

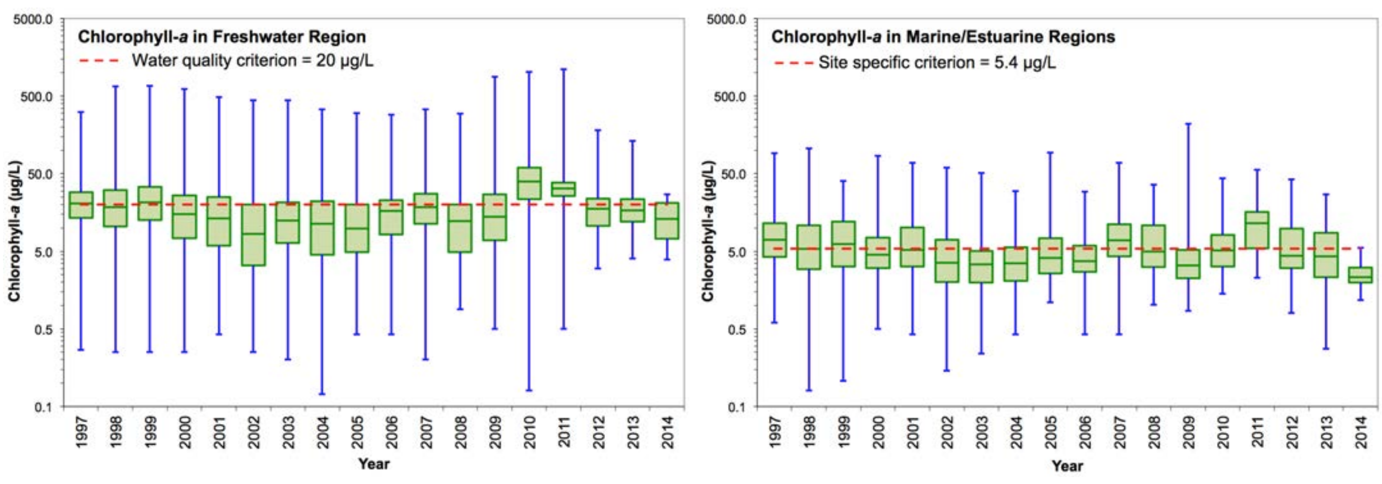


Figure 2.19 Yearly chlorophyll-a concentrations from 1997 to 2014 in the Lower St. Johns River mainstem for freshwater and marine/estuarine regions. The dashed red lines represent the chlorophyll-a thresholds. Data are presented as a box-and-whiskers plot with the green boxes indicating the median ±25% (middle 50% of the data). The median value is the value of the data that splits the data in half and is indicated by the horizontal green line in the center of the boxes. The green box above the median line contains the values for the next higher 25% of the data, and the green box below the median contains the values for the next lower 25% of the data. Blue whiskers indicate the minimum and maximum values in the data set. Note logarithmic scale on y-axis.

In 2013, the LSJR also experienced blooms, and 36% of the samples in the freshwater WBIDS had chlorophyll-a levels greater than 20 µg/L and 4% had levels greater than 40 µg/L (the nuisance bloom level). The marine/estuarine portion had 38% of the samples above the site-specific criterion of 5.4 µg/L, and 18% above the general 11 µg/L criterion, demonstrating continued elevated chlorophyll-a levels.

Chlorophyll-*a* data are measures that relate to abundance of all of the phytoplankton present. When high concentrations of chlorophyll-a are specifically from toxic cyanobacteria, then concerns about water toxicity are elevated. In October 2013 the St. Johns Riverkeeper reported that microcystin (a cyanotoxin) concentrations in several LSJR samples exceeded the World Health Organization's *moderate probability of adverse health effects in recreational water* guideline of 20 μg/L by 50-100 times (**Inclan 2013; Patterson 2013; St. Johns Riverkeeper 2013a**). Both of the toxin-sampling sites were in the estuarine region (Doctors Lake and Jacksonville University dock). This illustrates a limitation of the analysis in this report. While 0% of the 2013 estuarine samples in the analyzed data set were >40 μg/L chlorophyll-a (indicating a "nuisance bloom"), there were indeed recorded toxic events.

Since the LSJR continues to experience elevated chlorophyll-a levels compared to the benchmarks, and toxic events have occurred, the STATUS of the LSJR with respect to algal blooms is considered unsatisfactory and the TREND is unchanged.

2.4.5. Summary and Future Outlook

The average annual concentrations of chlorophyll-a in LSJR mainstem sites analyzed in this report do not indicate that algal growth is diminishing, nor do the annual appearances of blooms in the lakes, mainstem, and tributaries of the LSJRB in the last eight years. Evidence of elevated cyanotoxin levels also indicates significant impact from cyanobacteria. Much of the outlook for algal blooms is closely tied to that for nutrients. Reduced nutrient loading may be lowering concentrations of some forms of nutrients in the mainstem, but an accompanying reduction in algal blooms is not fully apparent.

The freshwater and marine/estuarine sections analyzed above are large geographical areas and thus give a big picture view of the LSJR over time. It is important to consider the complexity of the LSJR ecology and the difficulty in establishing healthy benchmarks and natural trends in a system with physical, chemical, and biological characteristics that naturally vary so widely in space and time. The FDEP has recently analyzed chlorophyll-a data from Racy Point, a freshwater location that it considers to be a "worst-case WBID", and reported the number of days per year that the location experiences a nuisance bloom (designated as chlorophyll-a values >40μg/L). From 1995-2013 the number of days per year that Racy point was >40 μg/L chlorophyll-a has been declining (**DEP 2014d**). While this analysis shows a decrease in the longevity of these blooms at this location, it still has recurring blooms. The next few years will be critical in determining when the considerable effort and expenditures to reduce nutrients in the LSJR are sufficient to limit algal blooms.

2.4.6. Recommendations for Research

Laboratory, mesocosm, and in-situ studies that analyze growth rates, toxin production, and bloom collapse of HAB cyanobacteria isolated from the LSJR as a function of varied nutrients, salinity, and temperature is essential to understanding blooms of the LSJR. Determining the sources of the phytoplankton (e.g. tributaries and sediments) would also be helpful in understanding the dynamics of HAB cyanobacteria in the LSJR.

2.5. Turbidity

2.5.1. Description and Significance

In its natural state, the St. Johns River, like other blackwater rivers, swamps and sloughs, has a high concentration of colored dissolved organic material (CDOM) that stains the water a dark brown color. The natural decay of plant materials stain the water to appear somewhat like tea in color. The St. Johns River, in particular, has a varied mix of dark-stained water from rainwater flow through the slow moving backwaters, and nearly clear contributions from large springs such as Blue Spring, De Leon Springs, Silver Springs (through the Ocklawaha River) and others. Heavy rains flush tannin-stained waters out of the slow-moving sloughs, swamps and backwaters and into the tributaries and mainstem of the LSJR. Color and turbidity are different properties of water, and both may arise from natural and anthropogenic sources. Turbidity is a reflection of how cloudy a water body appears, unlike the light absorption properties described by color, Turbidity is described on the Florida DEP website as:

*Turbidity is a measure of the suspended particles in water. Several types of material cause water turbidity, these include: silt or soil particles, tiny floating organisms, and fragments of dead plants. Human activities can be the cause of turbidity as well. Runoff from farm fields, stormwater from construction sites and urban areas, shoreline erosion and heavy boat traffic all contribute to high levels of turbidity in natural waters. These high levels can greatly diminish the health and productivity of estuarine ecosystems. (**DEP 2009b**)*

Three types of particles optically scatter light in the water column: suspended solids, particles of bacterial and algal origin, and micron-sized particles of CDOM. All are present in the dominantly freshwater portion of the LSJR (**Gallegos 2005**); however, the turbidity is dominated by both phytoplankton (mostly single-cell plants) and suspended solids from human impact (most often sediment or industrial waste) called non-algal particulates (NAP). NAP comes from such activities as sediment erosion from construction, land clearing and timber harvesting sites; stormwater runoff in urban and industrial areas, dredging, and solids from industrial outfalls (**Gallegos 2005**). During heavy rains, these sources may input a large volume of NAP into tributaries of the river. To address this, Florida has an extensive storm-water permitting program to limit stormwater impact. As discussed above, stormwater and drainage systems once considered non-point sources are now registered and permitted under the National Pollutant Discharge Elimination Program (NPDES) (**DEP 2009c**). In contrast to turbidity in freshwater, in more haline (salty) portions of the LSJR, scattering of light is dominantly from materials which are of larger size such as sediment (**Gallegos 2005**).

Periods of drought and rainfall can significantly affect turbidity. During periods of drought, flow from the tannin-stained backwaters decreases dramatically but the flow from the clear springs diminishes less. When this happens, the water may become significantly clearer and optical absorption by CDOM diminishes to below normal levels. With decreased CDOM and higher light penetration, phytoplankton are able to use the high nutrient concentrations more efficiently and readily undergo accelerated growth (**Phlips, et al. 2007**). In rainy periods after a drought, the St. Johns River may actually become more darkly stained from CDOM than usual, as rainfall moves the stalled and tannin-stained waters into the mainstem of the LSJR again. Under these conditions, CDOM absorption is the most influential optical property in a blackwater system such as the LSJR (**Phlips, et al. 2000**). In other events, and at specific locations and times, phytoplankton or NAP will dominate light loss in the water column and can be assessed by comparing turbidity levels with chlorophyll-a levels, which indicate algal content.

Turbidity levels in tributaries can increase during periods of drought under certain conditions, such as near constant industrial and WWTF output, algal blooms, or, more commonly after episodic rain events. For instance, sediment from construction, land clearing and timber harvesting sites, coupled with stormwater runoff, can be washed into the adjacent waters and overwhelm the other components. It is not difficult to spot sediment-laden water due to its appearance, often having a resemblance to "coffee with cream", as shown in Figure 2.20 for example.

Figure 2.20 Turbid water from McCoys Creek entering the LSJR on 17 July 2008. Courtesy of Christopher Ball.

Turbidity (algal and sediment particulate) and color are the two primary light attenuating factors in the LSJR that prevent light from reaching rooted submerged plants and thus hinder aquatic photosynthesis. Small plants and plantlike bacteria have evolved to float or suspend themselves in the upper levels of the water column to remain in the sunlight. At high concentration their combined scattering may not pass sufficient light to large plants attached to the bottom, like the river grasses that feed and serve as nursery habitat for juvenile fish and shrimp. Submerged aquatic vegetation (SAV) can suffer from a lack of light resulting from high turbidity and from sediment cover, from shading by smaller plants coating their leaf surfaces, or masking by floating algae. This has a large impact on animals, which depend on the grasses for food and shelter.

Figure 2.21 shows turbidity values in the LSJR since 1997. The box indicates the median +/- 25% of the data points (middle 50%). In several years, the highest value recorded was significantly higher than the interquartile range described by the green box; for those years, the high value is higher than the maximum value on the graph. A background turbidity level in the LSJR varies from single digit values to 12-15 Nephelometric Turbidity Units (NTUs) along the mainstem (**Armingeon 2008**), and anything over 29 NTUs above background is considered to exceed Florida state standards (62-302 F.A.C. **DEP 2013j**). While the state criterion for turbidity is 29 NTU above background, background levels vary in the LSJRB; therefore 29 NTU has been used as the threshold in the graphs.

Over this period there have been changes in measurement techniques, spatial sampling changes and many other factors, but clearly since 1993, the median value of turbidity in the LSJR has improved and is now below the acceptable limit.

Algal blooms (see previous section) can dominate turbidity when excess nutrient and sufficient background algal concentrations combine to produce prolific growth of the algal biomass. In this situation, the planktonic or filamentous algae can reduce visible depth, affecting the rooted submerged aquatic vegetation. This is referred to as a hypereutrophic condition. A good discussion of trophic state is found on the website of the Institute of Food and Agricultural Sciences at the University of Florida (**IFAS 2009**). While high trophic state index (TSI) values indicate high primary (plant) productivity, often that is part of an unbalanced ecosystem with very high nutrient and a large algal biomass that has large fluctuations in dissolved oxygen. A reduction in water clarity due to algal blooms is distinguishable from sediment turbidity by measurement of total chlorophyll-a at a level greater than 40 $\mu g/L$ (**SCCF 2014**) . This is not an optimum, healthy state for the entire ecosystem of the water body. Typical ranges for color in the LSJR are 50 to 200 Platinum Cobalt Units (PCU) in the mainstem, and depending on other circumstances (such as a recent rainfall after a drought) can be much higher in specific tributaries.

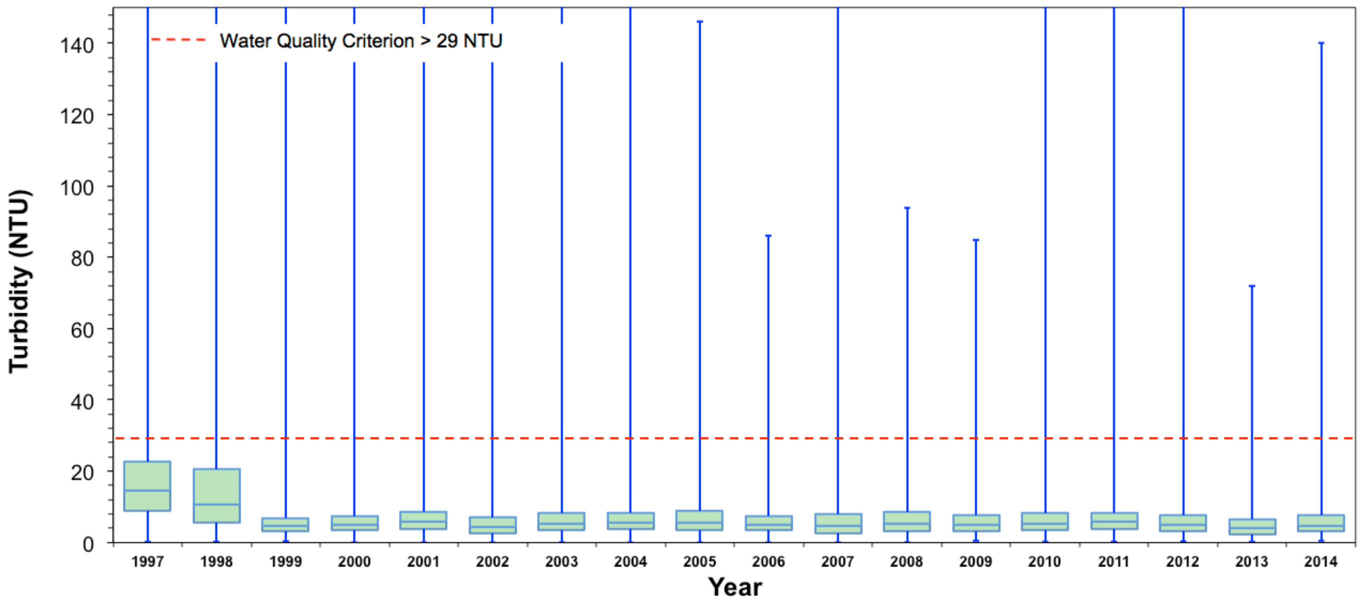


Figure 2.21 Yearly turbidity in the Lower St. Johns River Basin; 1997 - 2014.
Data are presented as a box-and-whiskers plot with the green boxes indicating the median value ±25% (middle 50%of data) and the blue whiskers indicating the minimum and maximum values in the data set.

2.5.2. *Data Sources*

The primary source for this evaluation is the Florida STORET database and the EPA-mandated reports required by the CWA such as the Florida 303(d) report of impaired waters. These reports become the basis for future water quality management and restoration efforts. These are publicly available online at **DEP 2004** and **DEP 2009f**. Previous versions of this report used EPA STORET data instead of the Florida STORET data used this year.

2.5.3. *Limitations*

In 1998, under the Florida standards (62-303 F.A.C. **DEP 2013j**), 16 water bodies in the LSRJB were listed as impaired for turbidity. Many of these were urban streams between the city of Jacksonville and Mayport, areas where urban runoff may have been a problem. Many have since been "delisted" in the CWA process. This may truly indicate substantial improvements, but it may also have been partly a function of the sampling timing during pre-hurricane drought conditions in 2004, which greatly reduced runoff and associated turbidity. For example: the earlier 303(d) report listed Cedar River and Goodbys Creek, as well as the mainstem of the river above the Dames Point area, at high risk of turbidity impairment, while later assessments, based on sampling in 2004, did not find turbidity impairments. Additionally, we have chosen to use virtually all the STORET data in spite of changes in methodology, uneven spatial and temporal sampling, and other issues that limit both the validity and generalization of the trend.

2.5.4. *Current Conditions*

Based on the current data available from STORET, turbidity conditions seem to be improving for the mainstem of the LSJR. In the tributaries (see Section 2.8), however, many reported violations of sediment control practices from work sites resulting in high turbidity events still exist, but progress is being made as evidenced by the following.

In May 2009, the following waterbodies were included in the final list of waterbodies proposed for delisting from the Florida 303(d) list: Goodbys Creek (WBID 2326), Cedar River (WBID 2262), Wills Branch (North Prong WBID 2282), Grog Branch (WBID 2407), and Butcher Pen Creek (WBID 2322) (**DEP 2009g**) These five waterbodies had been included in the previous draft delist list.

2.5.5. *Trend and Future Outlook*

Status: Satisfactory

Trend: Unchanged

Current management of turbidity in Duval County, for example, includes a requirement for land-disturbing activities to be overseen by a developer's certified staff, routine visits of land-disturbing sites, review of erosion control plans, and a citizen reporting mechanism. Heightened public awareness and improved engineering sediment control practices are bringing improvements in this area. Finable events over the past few years and the press they received will help keep the pressure on proper engineering practices. Vigilance in design of retention and detention ponds, sediment fences and public monitoring all can help. Reporting of turbidity events and sediment discharges near land-clearing and construction projects, particularly future Developments of Regional Impact (DRI) and monitoring existing municipal separate storm sewer system (MS4) areas for storm runoff should help ensure the best outcomes for the LSJR. Tributaries are particularly prone to turbidity events after a heavy rainfall.

2.6. Bacteria (Fecal Coliform)

2.6.1. Description and Significance

Fecal coliform bacteria are a natural component of digestive systems of birds and mammals. They aid in digestion, and are not normally considered harmful. In fact, sewage wastewater has been used to fertilize crops and replenish nutrients from depleted soils since ancient times (**Shuval, et al. 1990**). But due to discoveries that sewage wastewater spread disease, in modern times sewage wastewater has been treated and released back into natural waters.

Over the last four decades, the standards for sewage treatment have become ever more stringent, particularly with the passage of the CWA in 1977. As the EPA website notes:

> *Growing public awareness and concern for controlling water pollution led to enactment of the Federal Water Pollution Control Act Amendments of 1972. As amended in 1977, this law became commonly known as the Clean Water Act. The Act established the basic structure for regulating discharges of pollutants into the waters of the United States. It gave EPA the authority to implement pollution control programs such as setting wastewater standards for industry. The Clean Water Act also continued requirements to set water quality standards for all contaminants in surface waters (**EPA 2008**).*

This law required the nation's publicly owned sewer systems to remove 90% of the solid matter, and to disinfect the effluent (**Shabecoff 1988**), which was usually done with chlorine, to protect streams and rivers. Recently there has been a trend to move from chlorine to other oxidants (such as peroxides, oxygen, or ultraviolet light) because chlorine by-products may be harmful (**Jolley, et al. 1982**). The COJ passed Environmental Protection Board (EPB) Rule 3 to improve water quality in Duval County (1987). This led to a phase-out of the existing but less reliable local wastewater treatment plants (Figure 2.24), many of which were unable to meet the higher standards. Consolidation into larger regional treatment plants helped meet the higher standards.

Measurement of the effectiveness of wastewater treatment has historically involved the measurement of fecal coliform bacteria, among other water quality parameters. Fecal coliform bacteria are essentially an indicator species that provide an indication of whether human waste and associated pathogens, such as bacteria and viruses, are being sufficiently removed by wastewater treatment. Relatively few coliform species are pathogenic themselves.

Sources of fecal coliform bacteria in natural waters include wastewater treatment facility outflows, but that is only one of many sources. Fecal coliform bacteria reach the river from natural sources such as free-roaming wildlife and birds. Other sources include sanitary sewer overflows, domestic animal and pet contamination, human contamination from failing septic tanks, runoff and agricultural wastes from pasturelands. Wastewater outflows and sanitary sewer overflows are often called point sources because large amounts of waste can enter the river or tributary at a single point such as an outfall pipe. Nonpoint sources, in contrast, such as enter the watershed from a broad area.

Standards for bacteria levels in natural waters have been established and enforced for decades. The EPA has set standards (**EPA 1986**) for recreational water quality after earlier studies by the Centers for Disease Control and Prevention (CDC) determined that few people become sick with gastroenteritis by accidentally ingesting water with 200 coliform bacteria units per 100 milliliters of water while engaged in recreational activities (**Dufour 1984**). Current Florida fecal coliform exceedance criteria standards for recreational contact are as follows:

*Exceeding 800 colonies/100 milliliters for any single sample and a 30-day geometric mean exceeding 200 colonies/100 milliliters indicates that the water body sampled does not meet recreational water quality standards and contact should be avoided. Exceeding 400 colonies/100 milliliters in 10% of samples taken in a 30 day period indicates that the water body does not meet recreational water quality standards and caution should be exercised (**DEP 2009b**).*

2.6.2. *Current Status*

Status Rating: Unsatisfactory

Trend Rating: Conditions Unchanged

The mainstem of the LSJR, as opposed to its tributaries, has been monitored for fecal coliform and other water quality parameters at several sites from Welaka to Arlington (Jacksonville) under the FDEP "River-at-a-Glance" program, and these measurements show that through 2008 the mainstem of the LSJR is clearly in compliance for fecal coliform (**DEP 2009e**). Fecal coliform monitoring through "River-at-a-Glance" has been discontinued as of 2009.

Many of the LSJRB tributaries have elevated fecal coliform levels. Seventy-five tributaries are impaired for fecal coliform as of 2014, and of these, thirty-six have final fecal coliform TMDLs and are listed in Table 2.1 below. The TMDL process at FDEP is conducted in five-year cycles, and the order of TMDL establishment depends upon the level of tributary impairment.

Table 2.1 LSJRB Tributaries with Final Fecal Coliform TMDLs.

Big Davis Creek	Craig Creek	Greene Creek	Little Black Creek	Newcastle Creek	Sherman Creek
Big Fishweir Creek	Deep Bottom Creek	Greenfield Creek	McCoy Creek	Open Creek	Strawberry Creek
Block House Creek	Deer Creek	Grog Branch	Mill Creek	Ortega River	Terrapin Creek
Butcher Pen Creek	Durbin Creek	Hogan Creek	Miller Creek	Peters Creek	Trout River
Cedar River	Fishing Creek	Hopkins Creek	Miramar Creek	Pottsburg Creek	Wills Branch
Cormorant Branch	Goodbys Creek	Julington Creek	Moncrief Creek	Ribault River	Williamson Creek

Final fecal coliform BMAPs are in place for 25 of these tributaries: Craig Creek, McCoy Creek, Williamson Creek, Fishing Creek, Deep Bottom Creek, Moncrief Creek, Block House Creek, Hopkins Creek, Corporate Branch, Wills Branch, Sherman Creek, Greenfield Creek, Pottsburg Creek, Middle Trout River, Lower Trout River, Newcastle Creek, Hogan Creek, Butcher Pen Creek, Miller Creek, Miramar Creek, Big Fishweir Creek, Deer Creek, Terrapin Creek, Goodbys Creek, and Open Creek.

Progress reports on these BMAPs posted by FDEP in 2014 (**DEP 2014e; DEP 2014g**) present a mixed picture of fecal coliform bacteria levels in the tributaries. Data on the 2014 year was not available at the time of this writing. Methodologies for evaluating fecal coliform levels are undergoing change this year.

The original approach taken to report these results is the idea that the five-year goal of the BMAP is the achievement of a 50% reduction of the TMDL-determined median value, established during the 1996-2013 evaluation period. This goal addresses the issue of whether large-scale decreases in fecal coliform are being achieved. Table 2.2 below shows the tributaries, grouped by goal year, that have experienced a 50% or greater reduction in their median value up to 2013.

Table 2.2. LSJRB Tributaries with Fecal Coliform BMAPs with 50% or Greater Reduction in Median Value up to 2013.

Five-year Goal Year	Tributary	TMDL Median (number per 100 mL)	Median 2009-13 (number per 100 mL)	Percent Reduction of TMDL Median
2014	Deer Creek	2765	440	84.1%
	Goodby's Creek	3000	520	82.7%
	Hogan Creek	5000	1291	74.2%
	Miramar Creek	7000	1100	84.3%
	Newcastle Creek	2500	1000	60.0%
2015	Blockhouse Creek	2200	736	66.5%
	Cormorant Branch	1500	425	71.7%
	Deep Bottom Creek	2200	1081	50.9%
	Fishing Creek	1300	450	65.4%
	Greenfield Creek	1354	164	87.9%
	Lower Trout River	1000	110	89.0%
	McCoy Creek	2510	640	74.5%
	Middle Trout River	1184	360	69.6%
	Moncrief Creek	2600	560	78.5%
	Pottsburg Creek	800	248	69.0%
	Sherman Creek	1400	271	80.6%
	Wills Branch	4000	400	90.0%

Table 2.3 below shows the tributaries that have experienced less than a 50% reduction in their median value up to 2013.

Table 2.3. LSJRB Tributaries with Fecal Coliform BMAPs with less than 50% Reduction in Median Value up to 2013.

Five-year Goal Year	Tributary	TMDL Median (number per 100 mL)	Median 2009-13 (number per 100 mL	Percent Reduction of TMDL Median
2014	Big Fishweir Creek	3000	2215	26.2%
	Butcher Pen Creek	2400	2600	-8.3%
	Miller Creek	5000	4250	15.0%
	Open Creek	1000	550	45.0%
	Terrapin Creek	1367	700	48.8%
2015	Craig Creek	3000	2450	18.3%
	Hopkins Creek	1200	860	28.3%
	Williamson Creek	2400	2200	8.3%

In the 17 tributaries comprising Table 2.2, clearly a large reduction in fecal coliform levels has taken place. The 50% reduction will be likely well in hand by the goal year, barring unusual phenomena in each waterbody. In the eight tributaries comprising Table 2.3, some reduction has been observed in all but Butcher Pen Creek, and for Terrapin and Open Creeks, the 50% reduction levels hoped for in 2014 seem to be within reach.

Reductions of the median value are one approach to the evaluation of fecal coliform levels in the tributaries. Another approach entails the examination of the actual median values of fecal coliform in each tributary, as well as the number of times the level exceeds the threshold of 400 colonies per 100 mL in a year. Table 2.4 below presents all 25 tributaries with BMAPs, along with their median values in 2013 and the number of exceedances observed.

Table 2.4. LSJR Tributaries with Fecal Coliform BMAPs and Fecal Coliform Median Levels and Threshold Exceedances.

Tributary	2013 Median (number per 100 mL)	Number of exceedances out of total measurements
Big Fishweir Creek	2100	33 of 35
Blockhouse Creek	541	2 of 3
Butcher Pen Creek	1856	14 of 17
Cormorant Branch	571	22 of 32
Craig Creek	2950	29 of 30
Deep Bottom Creek	1757	28 of 36
Deer Creek	631	9 of 15
Fishing Creek	496	34 of 58
Goodbys Creek	515	12 of 18
Greenfield Creek	180	0 of 3
Hogan Creek	1532	35 of 36
Hopkins Creek	976	47 of 60
Lower Trout River	180	1 of 6
McCoy Creek	295	16 of 33
Middle Trout River	360	16 of 38
Miller Creek	3900	30 of 33
Miramar Creek	676	15 of 24
Moncrief Creek	207	2 of 6
Newcastle Creek	1532	16 of 22
Open Creek	355	3 of 12
Pottsburg Creek	991	4 of 7
Sherman Creek	360	36 of 74
Terrapin Creek	750	12 of 15
Williamson Creek	1150	29 of 34
Wills Branch	360	2 of 6

Table 2.4 indicates that many tributaries still experience very high numbers of exceedances of the acceptable threshold for fecal coliform levels. Big Fishweir Creek, Butcher Pen Creek, Craig Creek, Deep Bottom Creek, Hogan Creek, Hopkins Creek, Miller Creek, Newcastle Creek, Pottsburg Creek, Terrapin Creek, and Williamson Creek all exhibit high median values as well as large numbers of exceedances.

One subset of this group of tributaries is approaching threshold levels: Blockhouse Creek, Cormorant Branch, Deer Creek, Fishing Creek, Goodbys Creek, and Miramar Creek.

Notable exceptions are Greenfield Creek, the Lower Trout River, McCoy Creek, the Middle Trout River, Moncrief Creek, Open Creek, Sherman Creek, and Wills Branch. These eight waterbodies possess median values below the 400 number per 100 mL threshold, and they experience relatively few exceedances among their individual measurements. All except Open Creek have exceeded the 50% reduction in the TMDL median as well.

Generally BMAPs lay out projects and plans intended to reduce loading of the identified pollutant, to be executed by the key responsible parties. For fecal coliform BMAPs in this set of 25 tributaries, the responsible parties are COJ, JEA, the Florida Department of Transportation, the Florida Department of Health, Naval Station Mayport, and other relevant municipalities including the Cities of Atlantic Beach, Jacksonville Beach, and Neptune Beach. FDEP also plays a role in implementation of BMAP projects.

Because the primary sources of fecal coliform are stormwater, wastewater, and septic tanks, the projects undertaken to reduce fecal coliform usually address these types of water streams. Examples of projects undertaken to reduce fecal coliform include wastewater infrastructure and treatment improvements, construction of stormwater retention ponds, removal of illicit wastewater connections to waterbodies, and septic tank phaseout and replacement by connection to municipal sewage services. Dozens of projects on these tributaries have been completed since the start of these BMAPs. Yet clearly the above results indicate that while many projects have been completed, several tributaries remain significantly impaired for fecal coliform. Even where septic tanks have been phased out, other anthropogenic sources continue to contribute to coliform levels. Further understanding of these problems is being pursued by the responsible parties by programs such as Walk the WBID and Maps on the Table. These activities enable stakeholders to take a close look at persistent point or nonpoint sources in each tributary to understand more deeply where fecal coliform may be entering the water.

2.6.2.1. Conclusion

Fecal coliform bacteria are a significant problem in the LSJRB, and considerable effort is being made to remedy this problem by way of the state TMDL and BMAP processes. Many tributaries with elevated fecal coliform levels have undergone large reductions in TMDL loading, an encouraging sign, particularly in advance of the five-year BMAP milestone years. However, despite making large reductions, actual fecal coliform levels in many tributaries are persistently higher than the current rules for the water quality criterion.

Rules changes on bacteria are underway. New bacteria criteria are under development by FDEP, following a new Recreational Water Quality Criterion (RWQC) promulgated by US EPA in 2012. This new RWQC is specific for E. coli strains and enterococci, rather than fecal coliform. (**EPA 2012**). The revision of Florida's standards is in process (**DEP 2014i**).

2.7. Tributaries

2.7.1. About the Tributaries

Water quality data were examined in detail for 29 tributaries in the LSJRB. Their selection was based upon several factors. First, the basin was divided into the 11 Planning Units that were initially established by the SJRWMD and subsequently adopted by DEP (**DEP 2002**). These Planning Units include Crescent Lake, Etonia Creek, Black Creek, Deep Creek, Sixmile Creek, Julington Creek, the Ortega River, the Trout River, the Intracoastal Waterway, the north mainstem, and the south mainstem. Each Planning Unit is made up of several waterbodies (parts of the river system) referred to by their Waterbody Identifier (WBID). Then each Planning Unit was reviewed, in order to choose WBIDs for analysis. A WBID was selected for analysis if it had enough sampling sites at which data had been collected. Often, if a WBID was on the verified impaired list in 2004, 2009, or 2014 (**DEP 2014c**) it was selected for analysis. Some unimpaired WBIDs were chosen because they are historically important or used frequently for recreation.

For each of these 29 tributaries, data were extracted (by characteristic) from Florida STORET and organized by WBID. The datasets were filtered to remove data that was deemed to be "invalid" for one or more of the following reasons (values in quotes are written as they are found in Florida STORET data fields).

- Data identified as "LEGACY STORET" (data is reported from 1997 onward)
- Data reported as "Present<PQL" where no Practical Quantitation Limit (PQL) was listed
- Data reported as "Non-detect" where no Minimum Detection Level (MDL) was listed
- Data with a matrix of "Ground Water", "Surface Water Sediment," and "Unknown"

In previous reports, all "Non-detect" data had been removed. While seemingly a logical approach, the effect tends to bias the quartiles calculated in the data analysis on the high side. As a result, "Non-detect" data (and data reported as zero concentration) has been included in the data analysis here with a value MDL/2 (see **Helsel 2005**). In a similar manner, values listed as "Present<PQL", were included as (PQL+MDL)/2 if no "Actual value" was reported in the "Comments" field. If an "Actual value" was reported in the "Comments" field it was used instead.

In the 'About' sections for each of the 29 tributaries below, information/data was taken from the TMDL documents about each tributary respectively, the Florida DEP comprehensive verified impaired list (**DEP 2014c**), and the draft verified list (**DEP 2015b**) and delist list (**DEP 2015c**) from the recent Group 2 basins Cycle 3 assessment (**DEP 2015d**).

In the water quality data tables below, dissolved oxygen (DO) water quality criteria (WQC) where either based on Site Specific Alternate Criteria (SSAC) (**DEP 2014h**) for marine portions of the river or the new freshwater DO criteria based on DO saturation in water (DO_{sat}) (**DEP 2013e**). As both of these criteria definitions are calculation based, the WQCs indicated in the tables should be considered nominal values.

Finally, freshwater WQC's for metals were based off of 100 mg $CaCO_3$/L, the estimated hardness of the freshwater part of the LSJR (**Bielmyer 2015**) (see Section 5.2.1 for more information).

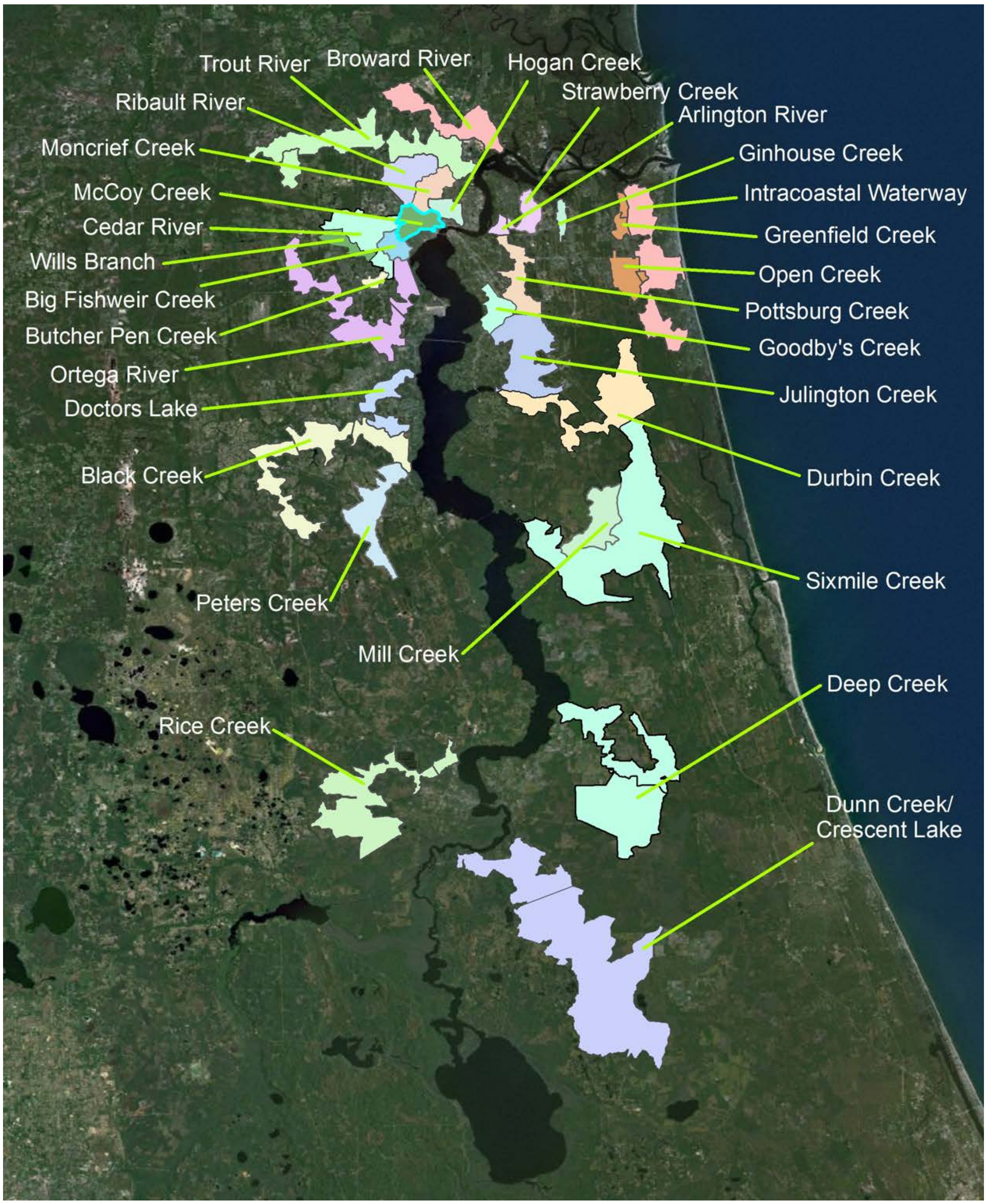


Figure 2.22 Tributaries of the Lower St. Johns River Basin

2.7.2. *Arlington River*

2.7.2.1. About the Arlington River

- East of downtown Jacksonville
- Primary Land Use: Residential
- Current TMDL reports: Nutrients, Mercury
- Verified Impaired 2014 (draft): Chlorophyll-a (med)
- WBID Area: 1.6 sq. mi.
- Beneficial Use: Class III M (Recreational – Marine)

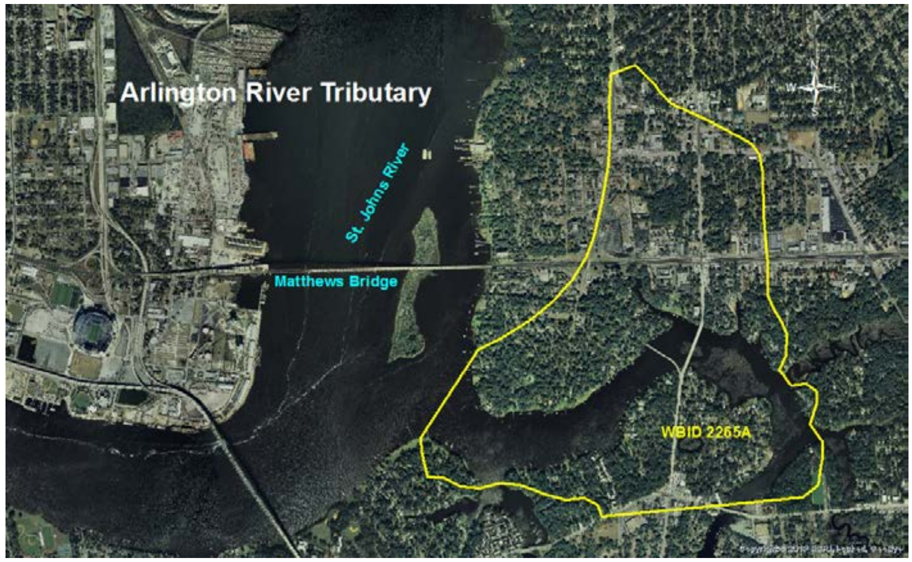


Figure 2.23 The Arlington River Tributary (WBID 2265A)

2.7.2.2. Data sources

Result data were downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010c**) in the Arlington River WBID 2265A (**DEP 2014f**) shown above. The filtered dataset was used to generate Table 2.5.

2.7.2.3. Discussion

Water quality data for the Arlington River are shown in Table 2.1. Average phosphorus levels were higher than the recently updated WQC (**EPA 2010a**) and the tributary has thus been identified as impaired for nutrients. Elevated levels of phosphorus may be a result of effluent from the Monterey WWTF that is discharged into the river, fertilizer runoff from the surrounding residential area, or other unidentified sources. A TMDL report for nutrients was finalized in 2009 (**Magley 2009d**).

The Arlington River was identified as being impaired for mercury, based on elevated levels of mercury in fish tissue, however this is being delisted (**DEP 2015c**) as it has been addressed by the statewide mercury TMDL (**DEP 2013a**).

Table 2.5 Water Quality Data for the Arlington River

Parameter	Water Quality Criteria (SW)	Concentration			Samples	Sampling Period
		Low	Average	High		
Dissolved Oxygen (mg/L)	≥4.0	3.12	7.51	12.59	105	1999 - 2008
Total Nitrogen (mg/L)	<1.54	0.31	1.08	2.53	65	1999 - 2008
Total Phosphorus (mg/L)	<0.12	0.05	0.13	0.27	63	1999 - 2008
Chlorophyll-a (µg/L)	<11	0.00	7.14	44.00	31	1999 - 2007
Arsenic (µg/L)	≤50	0.75	1.74	2.70	20	2007 - 2008
Cadmium (µg/L)	≤8.8	0.01	0.04	0.08	20	2007 - 2008
Copper (µg/L)	≤3.7	1.03	2.60	8.10	20	2007 - 2008
Lead (µg/L)	≤8.5	0.30	0.81	1.98	20	2007 - 2008
Nickel (µg/L)	≤8.3	0.31	0.67	2.36	20	2007 - 2008
Silver (µg/L)	≤0.92	0.01	0.03	0.04	20	2007 - 2008
Zinc (µg/L)	≤86	2.50	8.89	23.00	20	2007 - 2008
Fecal Coliform (log #/100 mL)	<2.6	0.40	1.53	2.78	38	2000 - 2007
Turbidity (NTU)	<29	1.40	8.28	34.00	90	1999 - 2007

Note: Hardness-dependent freshwater criteria for cadmium, copper, lead, nickel, and zinc were generated based on a hardness concentration of 100 mg/L. SW=saltwater (marine).

2.7.3. *Big Fishweir Creek*

2.7.3.1. About Big Fishweir Creek

- West of Downtown, South of I-10
- Primary Land Use: Residential
- Current TMDL reports:
  Fecal Coliform with BMAP (2009)
- Verified Impaired 2014 (draft):
  None
- WBID Area: 3.7 sq. mi.
- Beneficial Use: Class III F
  (Recreational – Freshwater)

Figure 2.24 Big Fishweir Creek (WBID 2280)

2.7.3.2. Data sources

Result data were downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010c**) in Big Fishweir Creek WBID 2280 (**DEP 2014f**) shown above. The filtered dataset was used to generate Table 2.6.

2.7.3.3. Discussion

Water quality data for Big Fishweir Creek are shown in Table 2.6. A TMDL report (**Wainwright and Hallas 2009a**) was released in 2009 to address Fecal coliform and as a result has been delisted from the Impaired Waters list (**DEP 2015c**) (*Note: the data analysis in the TMDL is based on different criteria than that used in this report*). Subsequently, a BMAP to address this issue was legally adopted (**DEP 2009d**). Annual Progress Reports for this BMAP were issued in 2011 (**DEP 2011b**), 2012 (**DEP 2012**) and 2013 (**DEP 2014e**); they list repairs, inspections, evaluations, and other improvements conducted by JEA, the Duval County Health Department, COJ, and FDOT.

Table 2.6 Water Quality Data for Big Fishweir Creek

Parameter	Water Quality Criteria (FW)	Concentration			Samples	Sampling Period
		Low	Average	High		
Dissolved Oxygen (mg/L)	34% sat. (~3.0)	0.10	4.86	13.32	412	1999 - 2014
Total Nitrogen (mg/L)	<1.54	0.27	0.90	3.00	54	1999 - 2007
Total Phosphorus (mg/L)	<0.12	0.05	0.14	0.60	70	1999 - 2007
Chlorophyll-a (μg/L)	<20	0.28	8.27	59.00	18	2007
Arsenic (μg/L)	≤50	0.11	1.23	4.10	20	2005 - 2007
Cadmium (μg/L)	≤0.3	0.01	3.07	105.00	58	2002 - 2007
Copper (μg/L)	≤9.3	0.02	3.68	50.00	68	2002 - 2007
Lead (μg/L)	≤3.2	0.00	8.08	50.00	65	2002 - 2007
Nickel (μg/L)	≤52	0.00	4.36	50.00	68	2002 - 2007
Silver (μg/L)	≤0.07	0.01	0.02	0.04	20	2005 - 2007
Zinc (μg/L)	≤120	0.04	10.59	50.00	70	2002 - 2007
Fecal Coliform (log #/100 mL)	<2.6	-0.52	3.23	5.41	451	1999 - 2014
Turbidity (NTU)	<29	0.00	7.21	52.00	140	1999 - 2013

Note: Hardness-dependent freshwater criteria for cadmium, copper, lead, nickel, and zinc were generated based on a hardness concentration of 100 mg/L. FW=freshwater.

2.7.4. *Black Creek*

2.7.4.1. About Black Creek

- West of the St Johns River at the Clay/Duval county line
- Primary Land Use: Forested
- Current TMDL reports: Lead – 2415B
- Verified Impaired 2014 (draft): DO (2415A med)
- WBID Area: 15.4 sq. mi.
- Beneficial Use: Class III F (Recreational – Freshwater)

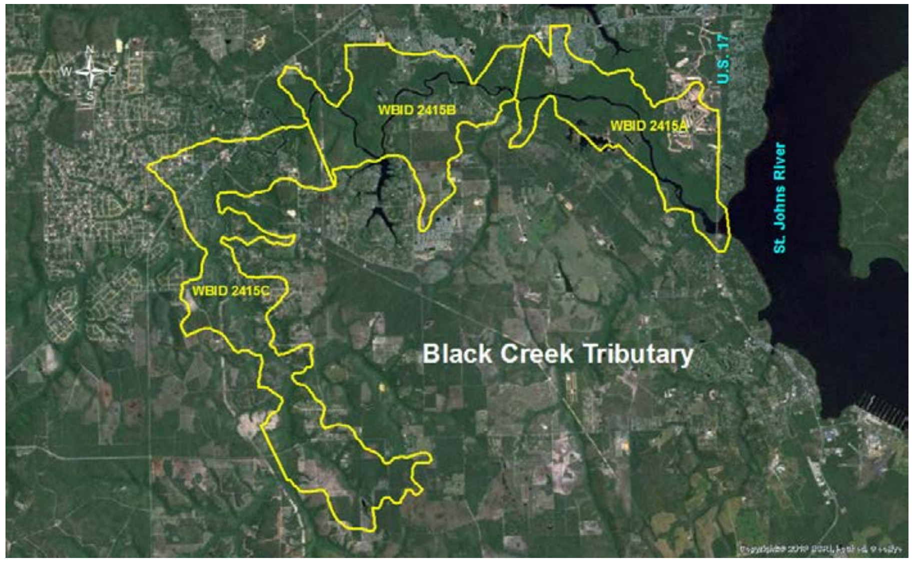


Figure 2.25 The Black Creek Tributary (WBID 2415A/B/C)

2.7.4.2. Data sources

Result data were downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010c**) in Black Creek WBID 2415A/B/C (**DEP 2014f**) shown above. The aggregate (all three WBIDs) filtered dataset was used to generate Table 2.7 and Figures 2.26 and 2.27.

2.7.4.3. Discussion

Water quality data for Black Creek are shown in Table 2.7. As compared to other tributaries in the LSJRB, Black Creek is less impacted for the majority of the assessed water quality parameters. Lead has been identified as impaired in Black Creek and a TMDL report was published in 2009 (**Lewis and Mandrup-Poulsen 2009**) to address this issue.

Table 2.7 Water Quality Data for Black Creek

Parameter	Water Quality Criteria (FW)	Concentration			Samples	Sampling Period
		Low	Average	High		
Dissolved Oxygen (mg/L)	34% sat. (~3.0)	0.50	6.23	12.45	561	1997 - 2014
Total Nitrogen (mg/L)	<1.54	0.07	0.73	2.11	448	1997 - 2014
Total Phosphorus (mg/L)	<0.12	0.03	0.10	0.51	801	1997 - 2014
Chlorophyll-a (µg/L)	<20	0.00	3.31	53.29	432	1997 - 2014
Arsenic (µg/L)	≤50	0.00	1.32	9.74	301	1997 - 2014
Cadmium (µg/L)	≤0.3	0.00	0.08	1.00	314	1997 - 2014
Copper (µg/L)	≤9.3	0.00	1.40	122.82	380	1997 - 2014
Lead (µg/L)	≤3.2	0.00	0.80	6.78	361	1997 - 2014
Nickel (µg/L)	≤52	0.00	1.21	20.55	363	1997 - 2014
Silver (µg/L)	≤0.07	0.00	0.13	8.44	244	1997 - 2014
Zinc (µg/L)	≤120	0.14	5.11	56.70	404	1997 - 2014
Fecal Coliform (log #/100 mL)	<2.6	0.18	1.42	2.96	98	2002 - 2013
Turbidity (NTU)	<29	0.80	6.55	368	482	1997 - 2014

Note: Hardness-dependent freshwater criteria for cadmium, copper, lead, nickel, and zinc were generated based on a hardness concentration of 100 mg/L. FW=freshwater.

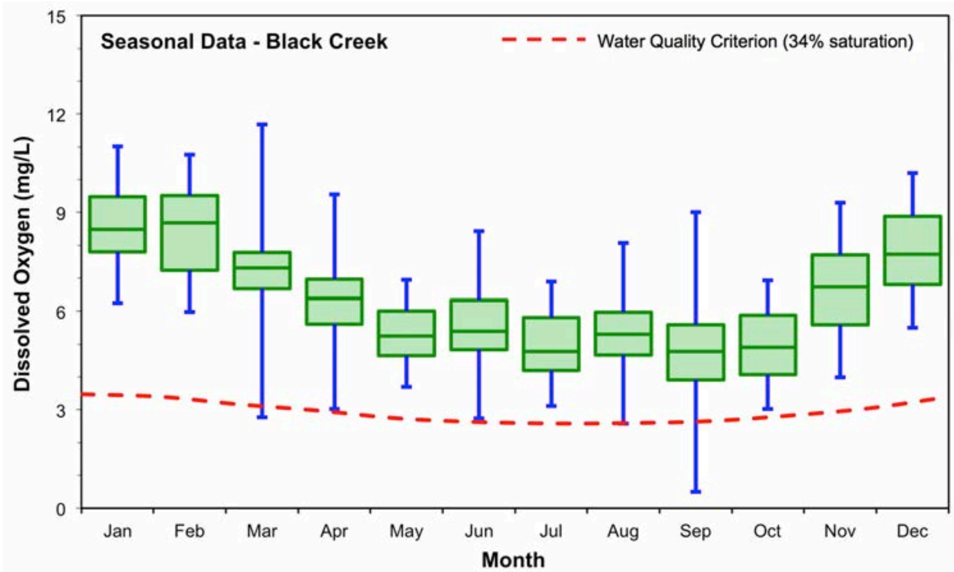


Figure 2.26 Monthly dissolved oxygen concentrations (data from 1997-2014) in Black Creek. Data are presented as a box-and-whiskers plot with the green boxes indicating the median ±25% (middle 50% of the data) and horizontal lines indicate the median values. Blue whiskers indicate the minimum and maximum values in the data set.

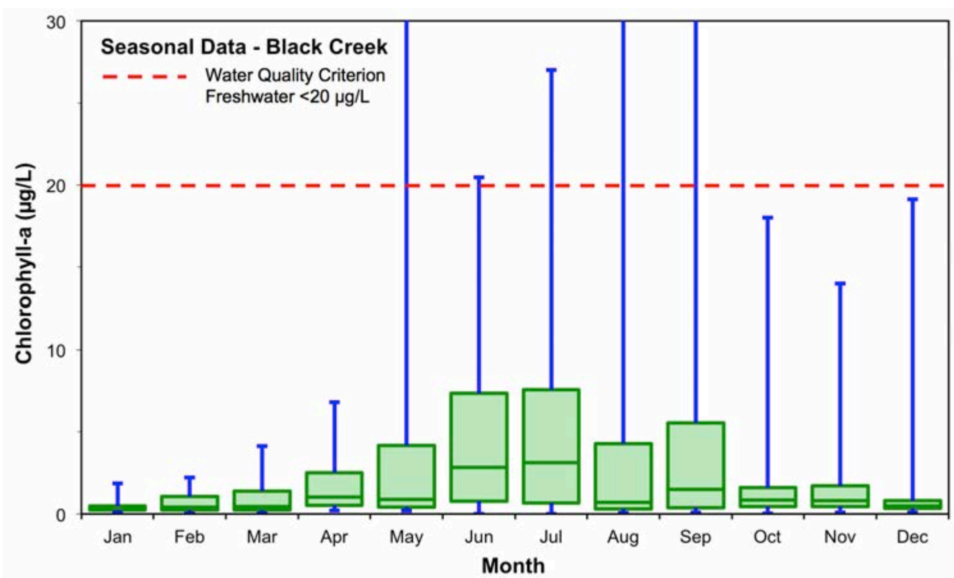


Figure 2.27 Monthly chlorophyll-a concentration (µg/L), based on data from 1997 through 2014 in Black Creek.

The maximum cadmium concentrations detected were more than threefold higher than the freshwater criterion (Table 2.7 above). In periods of higher salinity, elevated copper and nickel concentrations may be problematic, as they were detected at levels above WQC. The maximum silver concentration detected in Black Creek was more than 100 times the freshwater criterion and also substantially elevated above the SW criterion. The concentrations of silver detected have the potential for causing toxic effects to aquatic life in this area.

2.7.5. *Broward River*

2.7.5.1. About the Broward River

- Between downtown and Jacksonville International Airport (JIA)
- Primary Land Use: Residential/Forested
- Current TMDL reports: Mercury
- Verified Impaired 2014 (draft): DO (2191A med), Fecal Coliform (2191B med)
- WBID Area: 14.4 sq. mi.
- Beneficial Use: Class III M/ F (Marine - 2191B, Freshwater – 2191A)

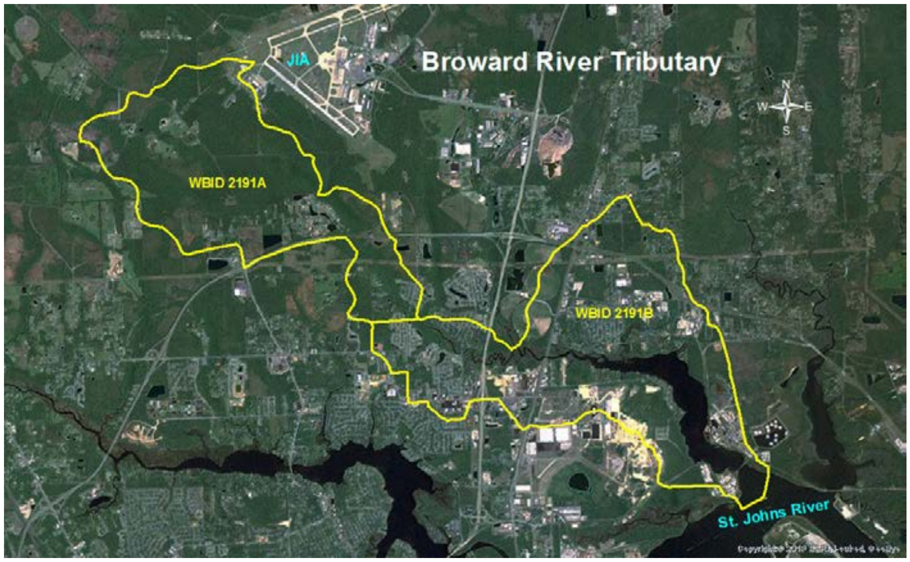


Figure 2.28 The Broward River Tributary (WBID 2191A/B)

2.7.5.2. Data sources

Result data were downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010c**) in Broward River WBID 2191A/B (**DEP 2014f**) shown above. The aggregate (both WBIDs) filtered dataset was used to generate Table 2.8.

2.7.5.3. Discussion

Water quality data for the Broward River are shown in Table 2.8. Due to recent split of WBID 2191 into a marine (2191B) and a freshwater (2191A) WBIDs the data is an aggregate of the and thus both FW and SW WQC's are included in the table. Average phosphorus levels were higher than the 2010 updated WQC (**EPA 2010a**). The maximum fecal coliform level at times exceeded the WQC of 2.6, which is the logarithm of the state maximum of 400 colony-forming-units per 100 mL (Table 2.4), and as a result WBID 2191B is considered impaired for fecal coliform. Dissolved oxygen is considered impaired in WBID 2191A. The Broward River was identified as being impaired for mercury, based on elevated levels of mercury in fish tissue, however this is being delisted (**DEP 2015c**) as it has been addressed by the statewide mercury TMDL (**DEP 2013a**).

Table 2.8 Water Quality Data for Broward River

Parameter	Water Quality Criteria	Concentration			Samples	Sampling Period
		Low	Average	High		
Dissolved Oxygen (mg/L)	34% sat. FW ≥4.0 SW	0.30	5.09	16.1	189	1999 - 2012
Total Nitrogen (mg/L)	<1.54	0.38	0.97	1.63	34	1999 - 2008
Total Phosphorus (mg/L)	<0.12	0.03	0.16	0.26	32	1999 - 2008
Chlorophyll-a (µg/L)	<20 FW <11 SW	0.43	10.22	52.0	24	2000 - 2007
Arsenic (µg/L)	≤50 FW ≤50 SW	0.52	1.54	2.60	27	1999 - 2007
Cadmium (µg/L)	≤0.3 FW ≤8.8 SW	0.01	0.63	5.00	28	1999 - 2007
Copper (µg/L)	≤9.3 FW ≤3.7 SW	0.38	1.65	5.00	28	1999 - 2007
Lead (µg/L)	≤3.2 FW ≤8.5 SW	0.10	3.34	20.00	27	1999 - 2008
Nickel (µg/L)	≤52 FW ≤8.3 SW	0.38	1.95	10.00	28	1999 - 2007
Silver	≤0.07 FW ≤0.92 SW	0.01	0.61	5.00	27	1999 - 2007
Zinc (µg/L)	≤120 FW ≤86 SW	2.50	7.33	20.0	28	1999 - 2007
Fecal Coliform (log #/100 mL)	<2.6	0.95	2.40	4.30	161	1999 - 2012
Turbidity (NTU)	<29	1.80	9.40	27.0	46	1999 - 2007

Note: Hardness-dependent freshwater criteria for cadmium, copper, lead, nickel, and zinc were generated based on a hardness concentration of 100 mg/L. FW=freshwater; SW=saltwater(marine).

2.7.6. *Butcher Pen Creek*

2.7.6.1. About Butcher Pen Creek

- A tributary of the Cedar River
- Primary Land Use: Residential
- Current TMDL reports:
  Fecal Coliform with BMAP (2009)
- Verified Impaired 2014 (draft):
  DO (high), Chlorophyll-a (high)
- WBID Area: 1.31 sq. miles
- Beneficial Use: Class III F
  (Recreational – Freshwater)

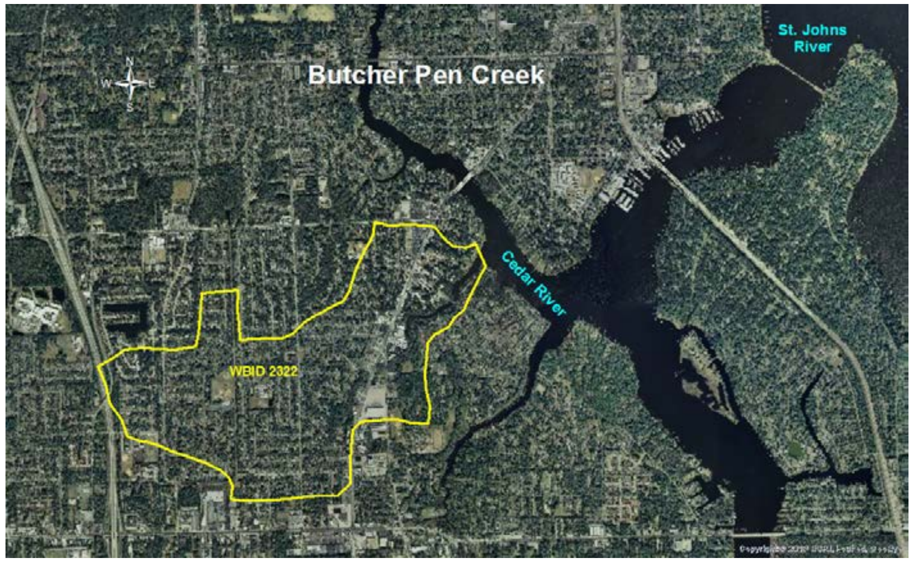


Figure 2.29 Butcher Pen Creek (WBID 2322)

2.7.6.2. Data sources

Result data were downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010c**) in Butcher Pen Creek WBID 2322 (**DEP 2014f**) shown above. The filtered dataset was used to generate Table 2.9.

2.7.6.3. Discussion

Water quality data for Butcher Pen Creek are shown in Table 2.4B. Average phosphorus levels were higher than the recently updated WQC (**EPA 2010a**). The average fecal coliform level exceeds the WQC of 2.6, which is the logarithm of the state maximum of 400 colony-forming-units per 100 mL (Table 2.9). As a result, a TMDL report was published in 2005 (**Wainwright 2005a**) to address this issue. Subsequently, a BMAP to address this issue was legally adopted (**DEP 2009d**). Annual Progress Reports for this BMAP were issued in 2011 (**DEP 2011b**), 2012 (**DEP 2012**) and 2013 (**DEP 2014e**); they list repairs, inspections, evaluations, and other improvements conducted by JEA, the Duval County Health Department, COJ, and FDOT.

Table 2.9 Water Quality Data for Butcher Pen Creek

Parameter	Water Quality Criteria (FW)	Concentration			Samples	Sampling Period
		Low	Average	High		
Dissolved Oxygen (mg/L)	34% sat. (~3.0)	0.20	4.73	10.7	256	1999 - 2014
Total Nitrogen (mg/L)	<1.54	0.60	1.39	3.06	28	2001 - 2007
Total Phosphorus (mg/L)	<0.12	0.10	0.26	0.97	28	2001 - 2007
Chlorophyll-a (µg/L)	<20	0.43	17.20	100	27	2002 - 2007
Arsenic (µg/L)	≤50	0.25	1.91	4.60	17	2007
Cadmium (µg/L)	≤0.3	0.01	0.04	0.13	17	2007
Copper (µg/L)	≤9.3	0.25	2.17	4.12	26	2004 - 2007
Lead (µg/L)	≤3.2	0.25	2.35	8.75	18	2004 - 2007
Nickel (µg/L)	≤52	0.50	1.06	2.93	17	2007
Silver	≤0.07	0.01	0.02	0.06	17	2007
Zinc (µg/L)	≤120	2.50	20.01	91.0	17	2007
Fecal Coliform (log #/100 mL)	<2.6	1.00	3.36	5.26	210	1999 - 2014
Turbidity (NTU)	<29	3.00	10.70	169	65	2001 - 2013

Note: Hardness-dependent freshwater criteria for cadmium, copper, lead, nickel, and zinc were generated based on a hardness concentration of 100 mg/L. FW=freshwater.

2.7.7. *Cedar River*

2.7.7.1. About the Cedar River

- At the I-10/I-295 Interchange
- Primary Land Use: Residential/Forested
- Current TMDL reports: Fecal/Total Coliform - 226)
- Verified Impaired 2014 (draft): Iron (med)
- WBID Area: 22.8 sq. mi.
- Beneficial Use: Class III F (Recreational – Freshwater)

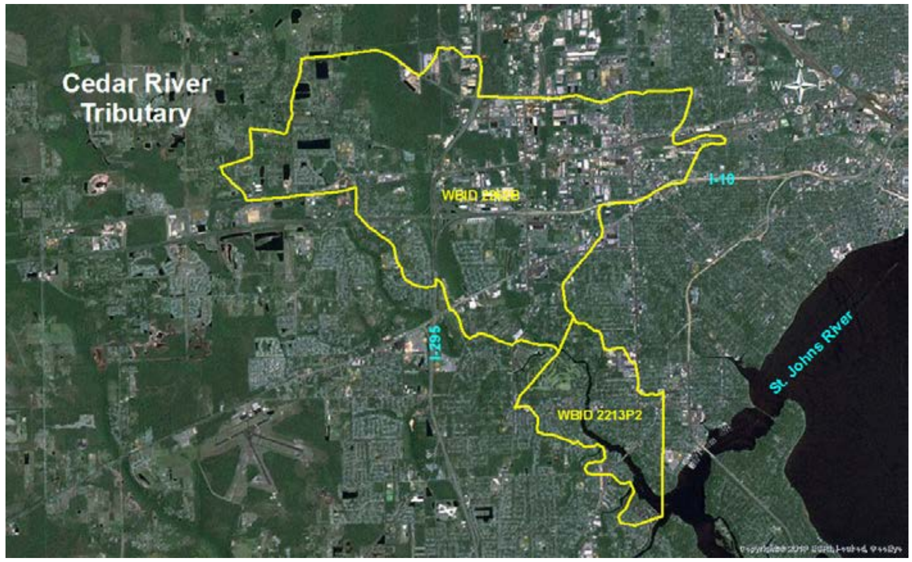


Figure 2.30 The Cedar River Tributary (WBID 2262 and 2213P2)

2.7.7.2. Data sources

Result data were downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010c**) in Cedar River WBID 2262 and 2213P2 (**DEP 2014f**) shown above. The filtered dataset was used to generate Table 2.10.

2.7.7.3. Discussion

Water quality data for the Cedar River are shown in Table 2.10. The Cedar River feeds into the Ortega River and thus is not directly a tributary of the St. Johns River. Even so, the Cedar River is tidal in nature varying in height by ~1 ft. over the course of a day (**SJRWMD 2010a**). Salinity levels, as influenced by tidal movement, are relatively low indicating that the Ortega River buffers the Cedar River significantly from marine water intrusion. Average dissolved oxygen levels were mostly above the WQC and stable across the river (Figure 2.31). Average total phosphorus levels were higher than the recently updated WQC (**EPA 2010a**), as were average levels of chlorophyll-a. Metal concentrations are mostly within acceptable limits, with the exception of copper and nickel, which are slightly elevated.

Table 2.10 Water Quality Data for the Cedar River

Parameter	Water Quality Criteria (FW)	Concentration			Samples	Sampling Period
		Low	Average	High		
Dissolved Oxygen (mg/L)	34% sat. (~3.0)	0.49	5.60	12.40	522	1998 - 2014
Total Nitrogen (mg/L)	<1.54	0.19	0.99	4.71	162	1998 - 2014
Total Phosphorus (mg/L)	<0.12	0.01	0.12	1.20	192	1998 - 2014
Chlorophyll-a (µg/L)	<20	0.28	21.15	140.0	127	1998 - 2014
Arsenic (µg/L)	≤50	0.005	3.84	43.70	102	1998 - 2014
Cadmium (µg/L)	≤0.3	0.001	1.51	137.0	125	1998 - 2014
Copper (µg/L)	≤9.3	0.02	3.60	50.00	163	1998 - 2014
Lead (µg/L)	≤3.2	0.00	4.56	50.00	164	1998 - 2014
Nickel (µg/L)	≤52	0.00	3.99	50.00	138	1998 - 2014
Silver (µg/L)	≤0.07	0.00	0.32	5.00	51	2000 - 2014
Zinc (µg/L)	≤120	0.04	16.78	114.57	160	1998 - 2014
Fecal Coliform (log #/100 mL)	<2.6	1.00	2.49	5.20	380	1999 - 2012
Turbidity (NTU)	<29	0.00	6.44	44.40	198	1998 - 2014

Note: Hardness-dependent freshwater criteria for cadmium, copper, lead, nickel, and zinc were generated based on a hardness concentration of 100 mg/L. FW=freshwater.

In 2004, Cedar River was identified as being impaired for both fecal and total coliforms (i.e. levels significantly above 400 CFU/100 mL) and as a result, a TMDL report was finalized in 2006 (**Magley 2006b**). (*Note: the data analysis in the TMDL is based on different criteria than that used in this report*). Currently, a Basin Management Action Plan (BMAP) to address this impairment is under development, but the timeframe for its release is currently unknown.

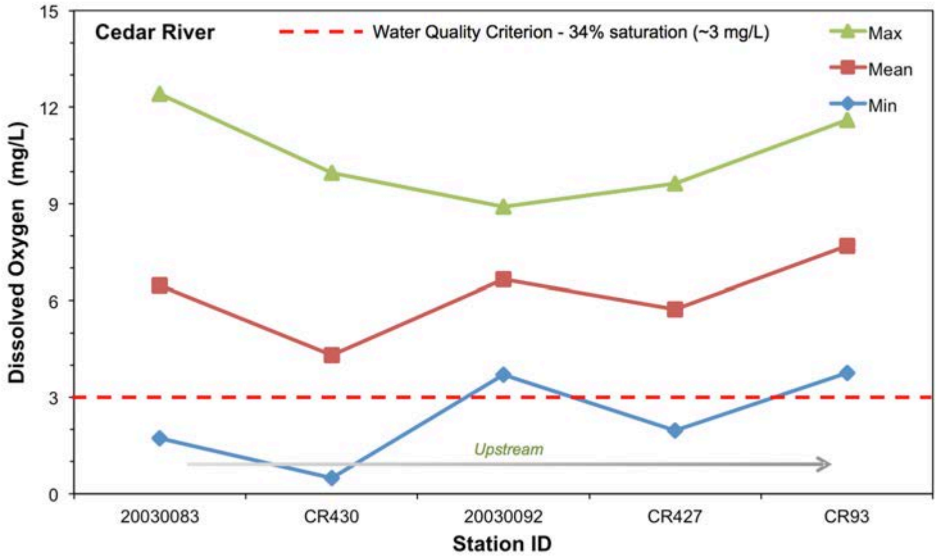


Figure 2.31 Variation of the dissolved oxygen in the Cedar River going upstream (left to right). Data from 1998-2014.

2.7.8. Deep Creek

2.7.8.1. <u>About Deep Creek</u>

- East of the St. Johns at Palatka
- Primary Land Use: Forested
- Current TMDL reports:
  Dissolved Oxygen – 2589 (draft)
- Verified Impaired 2014 (draft):
  DO (2549 med), Iron (2589 med),
  Historical chlorophyll-a (2589 med),
  Biology (SCI med)
- WBID Area: 60.5 sq. mi.
- Beneficial Use: Class III F
  (Recreational – Freshwater)

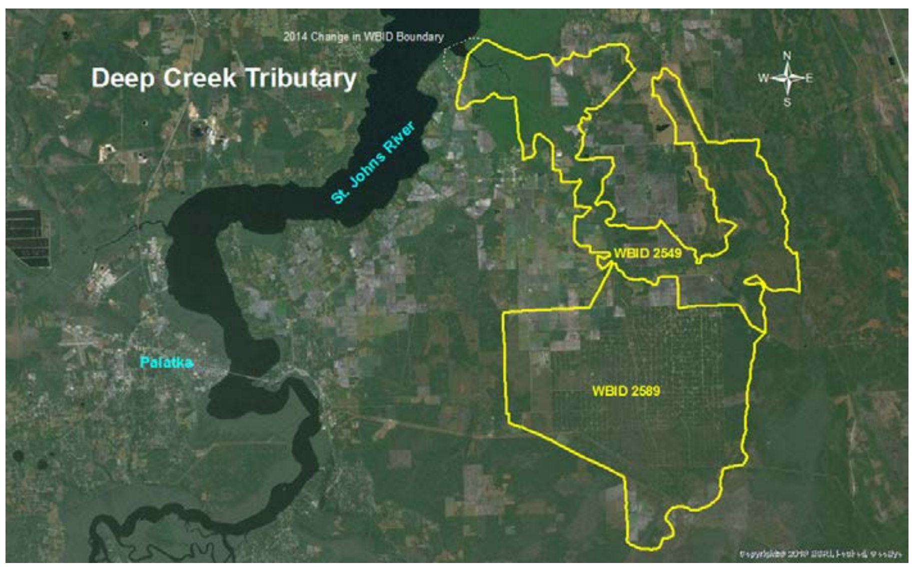


Figure 2.32 The Deep Creek Tributary (WBID 2549 and 2589)

2.7.8.2. <u>Data sources</u>

Data were downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010c**) in Deep Creek WBIDs 2549 and 2589 (**DEP 2014f**) shown above. The filtered dataset was used to generate Table 2.11.

2.7.8.3. <u>Discussion</u>

Water quality data for Deep Creek are shown in Table 2.11. Deep Creek is a tributary of the LSJR that drains the eastern banks around Hastings and Spuds, and thus receives substantial agricultural inputs, such as nutrients. Concentrations of total nitrogen were elevated (Figure 2.33) but not above the recently updated WQC (**EPA 2010a**), however levels of total phosphorus were significantly above the recommended WQC (Figure 2.34), and fluctuate seasonally. Non-point source rainwater runoff is likely the major cause of the elevated nitrogen/phosphorus concentrations in this area. Likewise, chlorophyll-a concentrations fluctuate, with relatively elevated levels in the summer months (Figure 2.35). Dissolved oxygen concentrations in these areas reflect these conditions, with lower dissolved oxygen concentrations observed in the summer months (Figure 2.36). In addition to nutrients, organic matter, temperature and community structure (i.e. number and types of plants and animal species), among other biotic factors, may contribute to the lower dissolved oxygen concentrations in these tributaries. As a consequence of the above factors/conditions, a draft TMDL report for dissolved oxygen was published in 2009 (**Magley 2009c**) for WBID 2589 (Sixteen Mile creek). Elevated concentrations of cadmium, copper, nickel, and silver have been detected in Deep Creek, as compared to the Class III WQC for metals. Iron has been added in the recent verified impaired list (**DEP 2015b**) but is potentially a natural condition in WBID 2589, and WBID 2549 has been identified as being impaired for biology, based on nutrient levels.

Table 2.11 Water Quality Data for Deep Creek

Parameter	Water Quality Criteria (FW)	Concentration			Samples	Sampling Period
		Low	Average	High		
Dissolved Oxygen (mg/L)	34% sat. (~3.0)	0.00	5.50	20.86	524	1997 - 2014
Total Nitrogen (mg/L)	<1.54	0.27	1.53	17.86	492	1997 - 2014
Total Phosphorus (mg/L)	<0.12	0.002	0.21	2.29	970	1997 - 2014
Chlorophyll-a (µg/L)	<20	0.00	4.48	90.1	297	1997 - 2014
Arsenic (µg/L)	≤50	0.00	2.11	17.04	236	1997 - 2014
Cadmium (µg/L)	≤0.3	0.00	0.11	1.28	244	1997 - 2014
Copper (µg/L)	≤9.3	0.00	1.90	14.78	326	1997 - 2014
Lead (µg/L)	≤3.2	0.00	0.67	7.79	160	1997 - 2013
Nickel (µg/L)	≤52	0.00	2.12	34.8	209	1997 - 2014
Silver (µg/L)	≤0.07	0.00	0.19	1.65	252	1997 - 2014
Zinc (µg/L)	≤120	0.31	7.29	49.7	331	1997 - 2014
Fecal Coliform (log #/100 mL)	<2.6	1.88	2.50	2.77	4	2002 - 2009
Turbidity (NTU)	<29	0.23	7.26	146	481	1997 - 2014

Note: Hardness-dependent freshwater criteria for cadmium, copper, lead, nickel, and zinc were generated based on a hardness concentration of 100 mg/L. FW=freshwater.

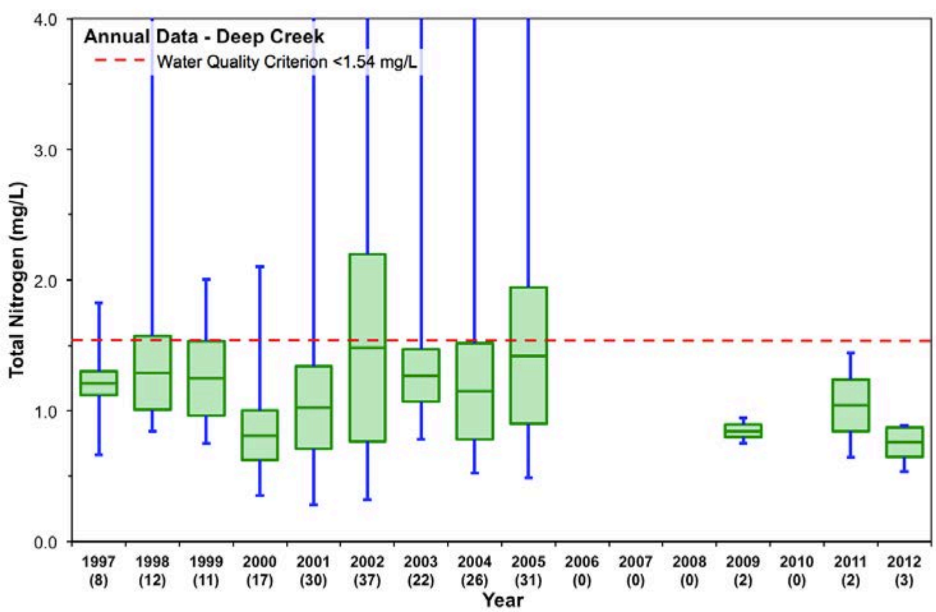


Figure 2.33 The yearly total nitrogen concentration in Deep Creek. All data are presented as a box-and-whiskers plot with green boxes indicating the median ±25% (middle 50% of the data) and horizontal lines indicating median values. Blue whiskers indicate minimum and maximum values in the data set.

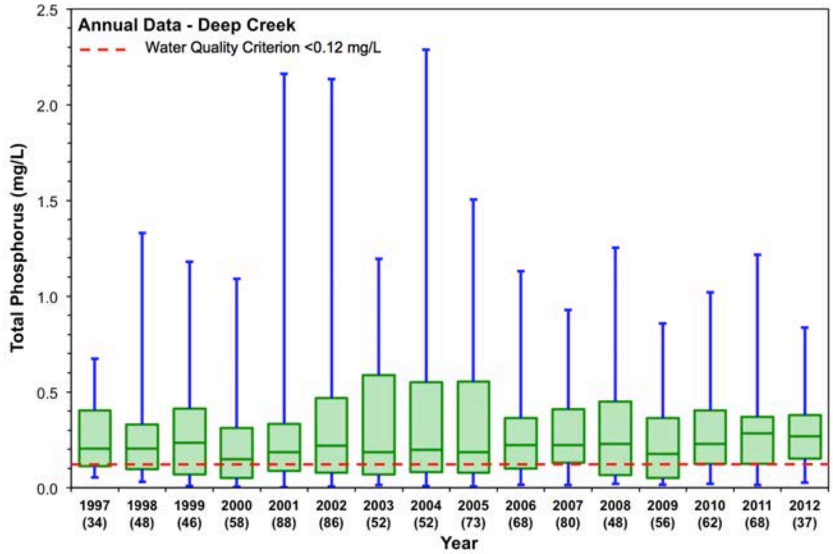


Figure 2.34 Yearly total phosphorus concentrations in Deep Creek. All data are presented as a box-and-whiskers plot with green boxes indicating the median ±25% (middle 50% of the data) and horizontal lines indicating median values. Blue whiskers indicate minimum and maximum values in the data set.

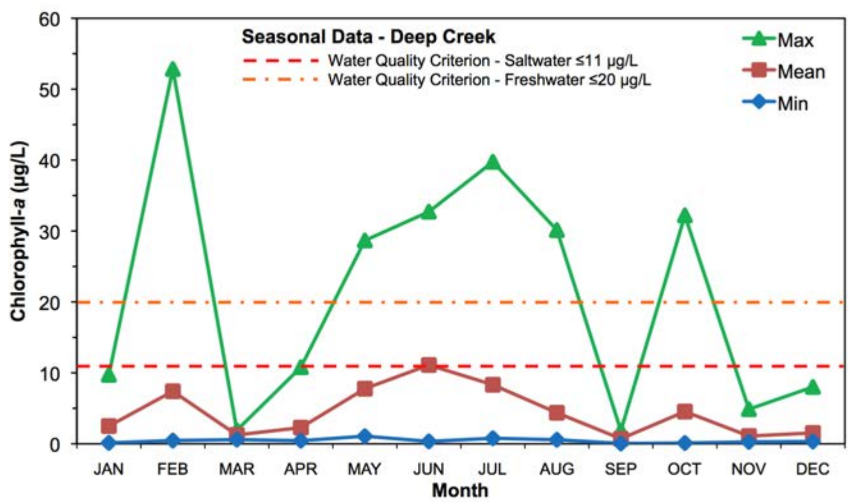


Figure 2.35 Monthly chlorophyll-a concentration (µg/L) in 1997 through 2008 in Deep Creek.

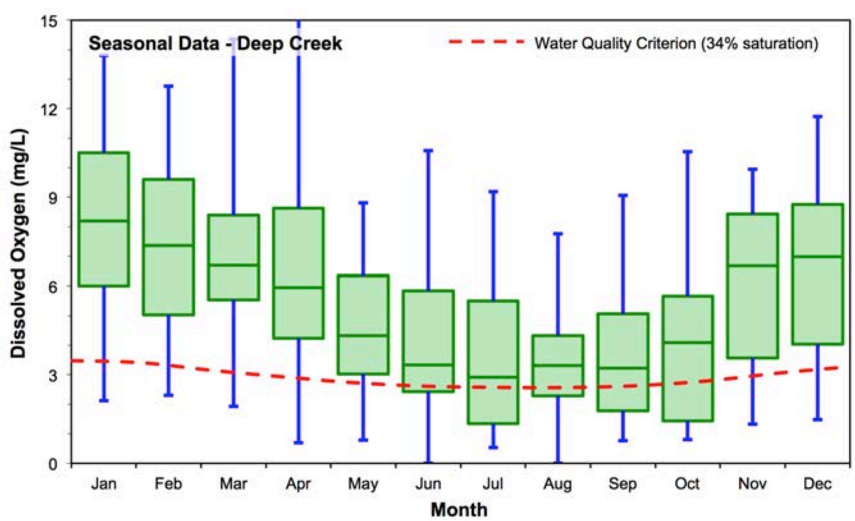


Figure 2.36 The monthly dissolved oxygen concentrations (data from 1977 to 2014) in Deep Creek.
Data are presented as a box-and-whiskers plot with green boxes indicating the median ±25% (middle 50% of the data) and horizontal lines indicating median values. Blue whiskers indicate minimum and maximum values in the data set.

2.7.9. Doctors Lake

2.7.9.1. About Doctors Lake

- West of the St. Johns River in Clay County
- Primary Land Use: Forested
- Current TMDL reports: Nutrient – 2389 (draft), DO/Nutrient – 2410 (draft), Silver – 2389/2410
- Verified Impaired 2014 (draft): TSI (2389 low), DO (2389 med), Fecal Coliform (2389 low)
- WBID Area: 8.4 sq. mi.
- Beneficial Use: Class III F (Recreational – Freshwater)

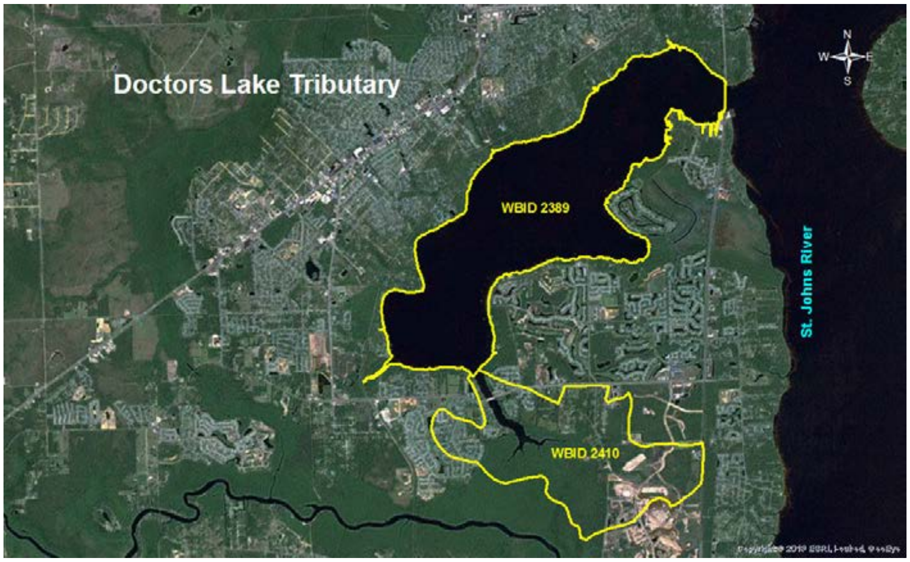


Figure 2.37 The Doctors Lake Tributary (WBID 2389 and 2410)

2.7.9.2. Data sources

Result data was downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010c**) in Doctors Lake WBIDs 2389 and 2410 (**DEP 2014f**) shown above. The filtered dataset was used to generate Table 2.12, with freshwater stream WQC's reported. These should be regarded as guidelines only because Swimming pen creek (2389) is accessed as a stream, Doctors Lake (2410) is accessed as a lake and has different WQC's.

2.7.9.3. Discussion

Water quality data for Doctors Lake are shown in Table 2.12. Although average total nitrogen and total phosphorus levels were within their WQC limits, average chlorophyll-a concentrations far exceeded the WQC, particularly in summer months (Figure 2.38), and average dissolved oxygen levels are well above the SSAC. Thus, Doctors Lake has been identified as being impaired for nutrients and a TMDL report to address this is currently in draft form (**Magley 2009b**). Elevated maximum arsenic, cadmium, copper, nickel, silver, and zinc concentrations were also measured in Doctors Lake, and as a result EPA ahs published a Silver TMDL (**EPA 2010b**). Doctors Lake is largely used for recreational activities such as boating, fishing, and waterskiing. These activities could account for some of the copper, nickel, and zinc contamination; however, the source of the other contamination is not clear. Two small creeks that flow from swampland merge and enter the lake from the south and the lake enters the mainstem of the LSJR from the northeast through the Doctors Inlet.

Table 2.12 Water Quality Data for Doctors Lake

Parameter	Water Quality Criteria (FW)	Concentration			Samples	Sampling Period
		Low	Average	High		
Dissolved Oxygen (mg/L)	34% sat. (~3.0)	0.00	8.04	15.54	1627	1997 - 2013
Total Nitrogen (mg/L)	<1.54	0.31	1.21	3.77	1023	1997 - 2013
Total Phosphorus (mg/L)	<0.12	0.001	0.07	0.48	2487	1996 - 2013
Chlorophyll-a (µg/L)	<20	0.36	28.51	198.54	1092	1997 - 2013
Arsenic (µg/L)	≤50	0.00	4.67	85.60	487	1997 - 2013
Cadmium (µg/L)	≤0.3	0.00	0.30	4.19	392	1997 - 2013
Copper (µg/L)	≤9.3	0.00	1.12	1.85	717	1997 - 2013
Lead (µg/L)	≤3.2	0.00	1.50	10.60	527	1997 - 2013
Nickel (µg/L)	≤52	0.00	3.84	117.80	303	1997 - 2013
Silver (µg/L)	≤0.07	0.00	0.31	4.38	333	1997 - 2013
Zinc (µg/L)	≤120	0.04	5.44	128.10	758	1997 - 2013
Fecal Coliform (log #/100 mL)	<2.6	No valid data available				
Turbidity (NTU)	<29	0.90	6.44	49.0	1095	1997 - 2013

Note: Hardness-dependent freshwater criteria for cadmium, copper, lead, nickel, and zinc were generated based on a hardness concentration of 100 mg/L. FW=freshwater.

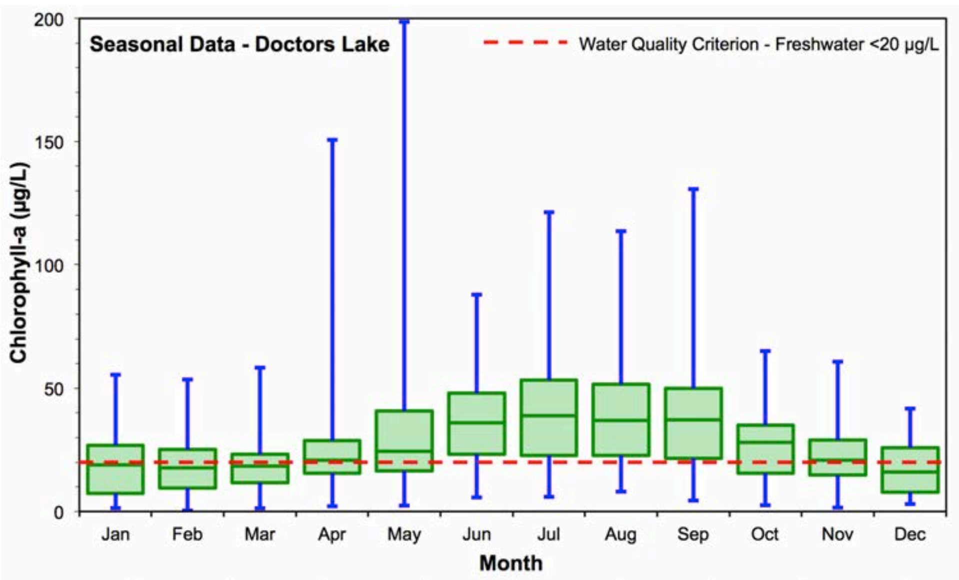


Figure 2.38 Monthly chlorophyll-a concentration (µg/L) in 1997 through 2014 in Doctors Lake. Data are presented as a box-and-whiskers plot with green boxes indicating the median ±25% (middle 50% of the data) and horizontal lines indicating median values. Blue whiskers indicate minimum and maximum values in the data set.

2.7.10. Dunns Creek/Crescent Lake

2.7.10.1. About Dunns Creek/Crescent Lake

- East of the St. Johns River in Flagler County
- Primary Land Use: Forested/Wetlands
- Current TMDL reports: Mercury – 2606B
- Verified Impaired 2014 (draft): Fecal Coliform (low), TSI (2606B med), Chlorophyll-a (med)
- WBID Area: 585 sq. mi.
- Beneficial Use: Class III F (Recreational – Freshwater)

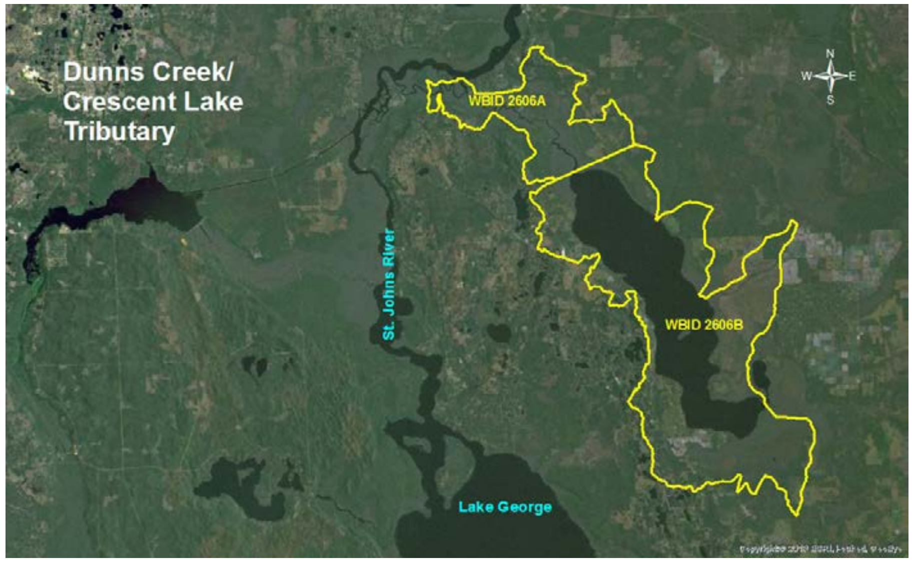


Figure 2.39 The Dunns Creek/Crescent Lake Tributary (WBID 2606A/B)

2.7.10.2. Data sources

Result data was downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010c**) in the Dunns Creek/Crescent Lake WBIDs 2606A/B (**DEP 2014f**) shown above. The filtered dataset was used to generate Table 2.13, with freshwater stream WQC's reported. These should be regarded as guidelines only because Dunns Creek (2606A) is accessed as a stream, Crescent Lake (2606B) is accessed as a lake and has different WQC's.

2.7.10.3. Discussion

Water quality data for Dunns Creek/Crescent Lake are shown in Table 2.13. This tributary is a significant non point-source contributor to nutrient levels in the St. Johns River (**Magley and Joyner 2008**). There is a significant variation of dissolved oxygen going upstream of the creek and into the lake as evidenced by the wider spread of values in Figure 2.40.

Dunns Creek (WBID 2606A) was identified as being impaired for mercury, based on elevated levels of mercury in fish tissue, however this is being delisted (**DEP 2015c**) as it has been addressed by the statewide mercury TMDL (**DEP 2013a**). In addition, a TMDL for Nutrients was recently drafted (**Bubel 2015**) for Crescent Lake based on it's Trophic State Index (TSI), calculated from the total nitrogen (TN), total phosphorous (TP), and chlorophyll-a levels.

Table 2.13 Water Quality Data for Dunns Creek/Crescent Lake

Parameter	Water Quality Criteria (FW)	Concentration			Samples	Sampling Period
		Low	Average	High		
Dissolved Oxygen (mg/L)	34% sat. (~3.0)	0.00	7.54	16.93	2468	1997 - 2014
Total Nitrogen (mg/L)	<1.54	0.30	1.29	3.24	1361	1997 - 2014
Total Phosphorus (mg/L)	<0.12	0.00	0.07	0.51	2888	1997 - 2014
Chlorophyll-a (µg/L)	<20	0.15	19.68	198.1	1437	1997 - 2014
Arsenic (µg/L)	≤50	0.00	1.54	5.77	407	1997 - 2014
Cadmium (µg/L)	≤0.3	0.00	0.07	0.61	363	1997 - 2014
Copper (µg/L)	≤9.3	0.00	0.60	1.1	669	1997 - 2014
Lead (µg/L)	≤3.2	0.00	0.81	5.36	427	1997 - 2014
Nickel (µg/L)	≤52	0.00	1.20	53.26	320	1997 - 2014
Silver (µg/L)	≤0.07	0.00	0.14	1.16	320	1997 - 2014
Zinc (µg/L)	≤120	0.00	3.41	133.7	724	1997 - 2014
Fecal Coliform (log #/100 mL)	<2.6	-0.30	0.65	3.68	124	1998 - 2013
Turbidity (NTU)	<29	0.65	5.47	35.40	1454	1997 - 2014

Note: Hardness-dependent freshwater criteria for cadmium, copper, lead, nickel, and zinc were generated based on a hardness concentration of 100 mg/L. FW=freshwater.

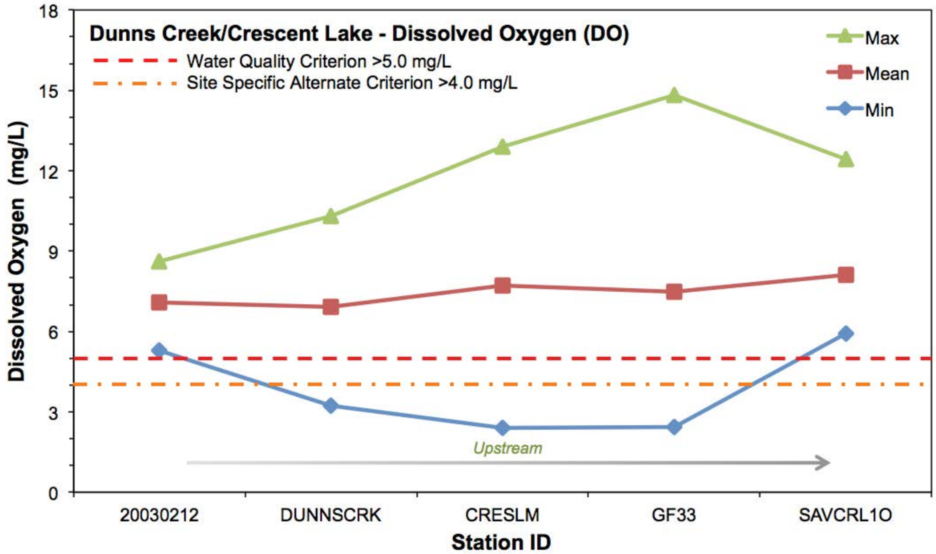


Figure 2.40 Variation of the dissolved oxygen in Dunns Creek and Crescent Lake going upstream (left to right)
Note: The data in this graph are not consistent in sampling interval and/or timeframe.

2.7.11. Durbin Creek

2.7.11.1. About Durbin Creek

- East of the St. Johns River
  South of I-295
- Primary Land Use: Forested
- Current TMDL reports:
  Fecal Coliform
- Verified Impaired 2014 (draft):
  None
- WBID Area: 26.2 sq. mi.
- Beneficial Use: Class III F
  (Recreational – Freshwater)

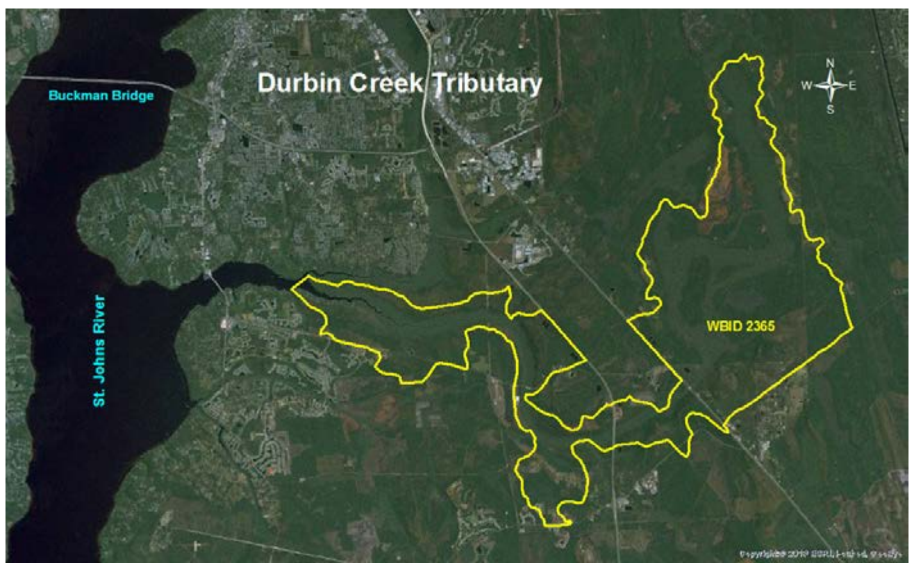


Figure 2.41 The Durbin Creek Tributary (WBID 2365)

2.7.11.2. Data sources

Result data were downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010c**) in the Durbin Creek WBID 2365 (**DEP 2014f**) shown above. The filtered dataset was used to generate Table 2.14.

2.7.11.3. Discussion

Water quality data for Durbin Creek are shown in Table 2.14. Average dissolved oxygen levels in Durbin Creek are relatively low when compared to other tributaries of the LSJRB. However, no causative pollutant (specific environmental condition) has been identified and thus no TMDL report is required as it is the "natural condition" of the waterbody (**DEP 2009g**). Currently, a TMDL report is available for fecal coliform in Durbin Creek (**Magley 2006a**). (*Note: the data analysis in the TMDL is based on different criteria than that used in this report*).

Table 2.14 Water Quality Data for Durbin Creek

Parameter	Water Quality Criteria (FW)	Concentration			Samples	Sampling Period
		Low	Average	High		
Dissolved Oxygen (mg/L)	34% sat. (~3.0)	0.00	4.03	9.60	295	1997 - 2014
Total Nitrogen (mg/L)	<1.54	0.28	1.15	3.54	155	1997 - 2014
Total Phosphorus (mg/L)	<0.12	0.00	0.07	0.48	187	1997 - 2014
Chlorophyll-a (µg/L)	<20	0.00	1.44	32.60	99	1997 - 2014
Arsenic (µg/L)	≤50	0.00	0.75	6.11	78	1997 - 2014
Cadmium (µg/L)	≤0.3	0.00	0.75	50.00	110	1997 - 2014
Copper (µg/L)	≤9.3	0.00	1.80	50.00	142	1997 - 2014
Lead (µg/L)	≤3.2	0.00	3.72	50.00	136	1997 - 2013
Nickel (µg/L)	≤52	0.00	2.97	50.00	136	1997 - 2014
Silver (µg/L)	≤0.07	0.00	0.14	0.72	38	2004 - 2014
Zinc (µg/L)	≤120	0.00	5.87	50.00	152	1997 - 2014
Fecal Coliform (log #/100 mL)	<2.6	-0.30	1.99	3.67	193	1999 - 2012
Turbidity (NTU)	<29	0.40	3.82	26.00	175	1997 - 2014

Note: Hardness-dependent freshwater criteria for cadmium, copper, lead, nickel, and zinc were generated based on a hardness concentration of 100 mg/L. FW=freshwater.

2.7.12. Ginhouse Creek

2.7.12.1. <u>About Ginhouse Creek</u>

- South of the St. Johns River just west of Craig Airfield
- Primary Land Use: Residential
- Current TMDL reports: None
- Verified Impaired 2014 (draft): Fecal Coliform (med)
- WBID Area: 2.0 sq. mi.
- Beneficial Use: Class III F (Recreational – Freshwater)

Figure 2.42 The Ginhouse Creek Tributary (WBID 2248)

2.7.12.2. <u>Data sources</u>

Result data were downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010c**) in Ginhouse Creek WBID 2248 (**DEP 2014f**) shown above. The filtered dataset was used to generate Table 2.15.

2.7.12.3. <u>Discussion</u>

Water quality data for Ginhouse Creek are shown in Table 2.15, note however that no metals data were available. Average phosphorus levels were higher than the recently updated WQC (**EPA 2010a**); however, average total nitrogen, chlorophyll-a and dissolved oxygen levels were within acceptable limits. Average fecal coliform levels are elevated and above the WQC, and thus Ginhouse Creek has been identified as impaired for fecal coliform (**DEP 2014c**).

Table 2.15 Water Quality Data for Ginhouse Creek

Parameter	Water Quality Criteria (FW)	Concentration Low	Concentration Average	Concentration High	Samples	Sampling Period
Dissolved Oxygen (mg/L)	34% sat. (~3.0)	0.34	5.44	11.04	161	1999 - 2014
Total Nitrogen (mg/L)	<1.54	0.49	1.09	2.52	30	2005 - 2014
Total Phosphorus (mg/L)	<0.12	0.06	0.11	0.62	30	2005 - 2014
Chlorophyll-a (µg/L)	<20	0.31	9.67	94.0	30	2005 - 2014
Arsenic (µg/L)	≤50	No valid data available				
Cadmium (µg/L)	≤0.3	No valid data available				
Copper (µg/L)	≤9.3	No valid data available				
Lead (µg/L)	≤3.2	No valid data available				
Nickel (µg/L)	≤52	No valid data available				
Silver (µg/L)	≤0.07	No valid data available				
Zinc (µg/L)	≤120	No valid data available				
Fecal Coliform (log #/100 mL)	<2.6	0.70	2.68	5.18	120	1999 - 2013
Turbidity (NTU)	<29	0.60	4.95	20.00	43	2005 - 2014

Note: Hardness-dependent freshwater criteria for cadmium, copper, lead, nickel, and zinc were generated based on a hardness concentration of 100 mg/L. FW=freshwater.

2.7.13. Goodbys Creek

2.7.13.1. About Goodbys Creek

- East of the St. Johns River opposite NAS Jacksonville
- Primary Land Use: Residential
- Current TMDL reports: Fecal Coliform with BMAP (2009)
- Verified Impaired 2014 (draft): None
- WBID Area: 5.1 sq. mi.
- Beneficial Use: Class III F (Recreational – Freshwater)

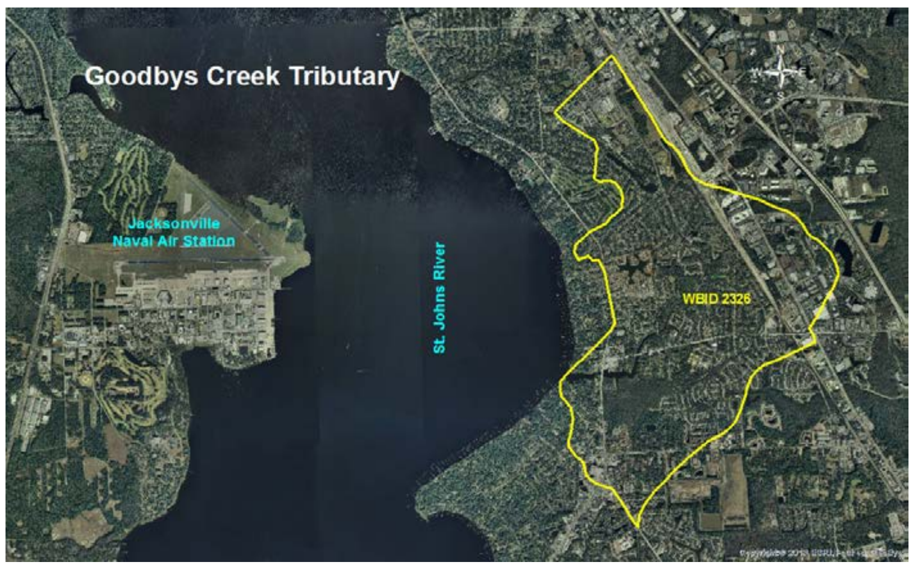


Figure 2.43 The Goodbys Creek Tributary (WBID 2326)

2.7.13.2. Data sources

Result data were downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010c**) in Goodbys Creek WBID 2326 (**DEP 2014f**) shown above. The filtered dataset was used to generate Table 2.16.

2.7.13.3. Discussion

Water quality data for Goodbys Creek are shown in Table 2.16. Average phosphorus levels in Goodbys Creek exceeded the recently updated WQC (**EPA 2010a**); however, average total nitrogen, dissolved oxygen and chlorophyll-a concentrations were within acceptable limits. The fecal coliform level, averaged over all the stations in Goodbys Creek, is below the critical level of 2.6, which is the logarithm of the state maximum of 400 colony-forming-units per 100 mL. Analysis by station is shown in Figure 2.44, going from the furthest downstream, within the mainstem of the St. Johns River, to the furthest upstream. The average remains at or above the state maximum until station 20030899, near Old Kings Road.

A TMDL report is available for fecal coliform in Goodbys Creek (**Wainwright 2005b**). (*Note: the data analysis in the TMDL is based on different criteria than that used in this report*). Subsequently, a BMAP for Goodbys Creek was legally adopted in 2009 (**DEP 2009d**). Annual Progress Reports for this BMAP were issued in 2011 (**DEP 2011b**), 2012 (**DEP 2012**), and 2013 (**DEP 2013h**); they list repairs, inspections, evaluations, and other improvements conducted by JEA, the Duval County Health Department, COJ, and FDOT.

Table 2.16 Water Quality Data for Goodbys Creek

Parameter	Water Quality Criteria (FW)	Concentration			Samples	Sampling Period
		Low	Average	High		
Dissolved Oxygen (mg/L)	34% sat. (~3.0)	0.20	5.05	12.35	335	1999 - 2014
Total Nitrogen (mg/L)	<1.54	0.34	0.77	2.06	65	1999 - 2012
Total Phosphorus (mg/L)	<0.12	0.01	0.05	2.04	108	1999 - 2012
Chlorophyll-a (µg/L)	<20	0.35	5.21	60.00	60	2002 - 2012
Arsenic (µg/L)	≤50	1.97	9.86	19.10	21	2004 - 2005
Cadmium (µg/L)	≤0.3	0.00	0.18	2.30	37	2003 - 2005
Copper (µg/L)	≤9.3	0.07	1.18	5.22	33	2003 - 2005
Lead (µg/L)	≤3.2	0.01	0.68	4.95	28	2003 - 2005
Nickel (µg/L)	≤52	0.00	1.36	6.47	35	2003 - 2005
Silver (µg/L)	≤0.07	0.04	0.18	0.50	8	2004 - 2005
Zinc (µg/L)	≤120	0.24	3.64	16.12	45	2003 - 2005
Fecal Coliform (log #/100 mL)	<2.6	0.65	2.67	4.63	258	1999 - 2014
Turbidity (NTU)	<29	2.00	8.06	59.40	76	1999 - 2013

Note: Hardness-dependent freshwater criteria for cadmium, copper, lead, nickel, and zinc were generated based on a hardness concentration of 100 mg/L. FW=freshwater.

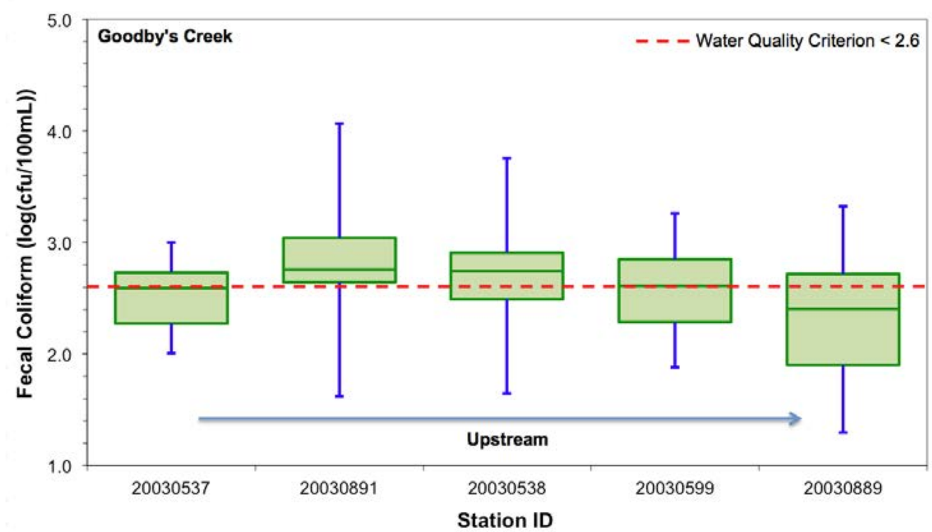


Figure 2.44 Fecal coliform in Goodbys Creek from downstream to upstream. Data are presented as the log of number of fecal coliform bacteria per 100 mL; the maximum, mean, and minimum values at each station are shown.

2.7.14. Greenfield Creek

2.7.14.1. About Greenfield Creek

- West of the Intracoastal Waterway
- Primary Land Use: Residential
- Current TMDL reports:
  Fecal Coliform with BMAP (2010)
- Verified Impaired 2014 (draft):
  Mercury (eval)
- WBID Area: 2.9 sq. mi.
- Beneficial Use: Class III F
  (Recreational – Freshwater)

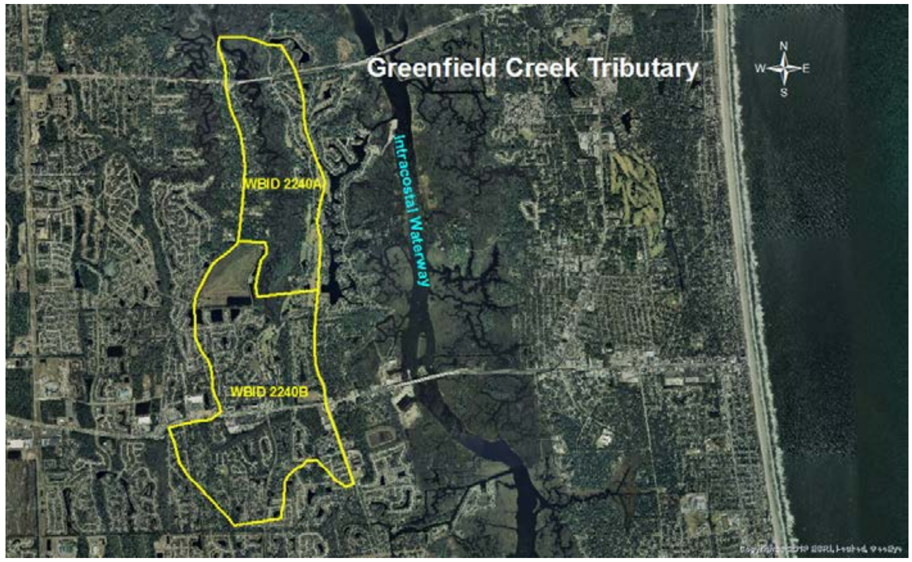


Figure 2.45 Greenfield Creek (WBID 2240A/B)

2.7.14.2. Data sources

Result data were downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010c**) in Greenfield Creek WBID 2240A/B (**DEP 2014f**) shown above. The filtered dataset was used to generate Table 2.17.

2.7.14.3. Discussion

Water quality data for Greenfield Creek are shown in Table 2.17. Average phosphorus levels were higher than the recently updated WQC (**EPA 2010a**) and average total nitrogen, dissolved oxygen and chlorophyll-a concentrations were within acceptable limits. *(Note: the datasets for these parameters are relatively small in comparison to other parts of the basin).* Dissolved oxygen has been identified as impaired (**DEP 2009f**) in Greenfield Creek. Recently a TMDL report (**Wainwright and Hallas 2009a**) was released to address fecal coliform.

The BMAP for Greenfield Creek (**DEP 2010b**) was legally adopted in August 2010. It describes sources of fecal coliform in the watershed, and completed and ongoing activities conducted by state and local agencies that are anticipated to reduce fecal coliform loading in the tributary. The Greenfield Creek watershed does not contain any permitted point sources for industrial wastewater. It contains the Girvin Road Landfill, which has been inactive since 1992; this landfill received not only solid waste, but sludge from the Neptune Beach Sewage Treatment Plant. The watershed also contains numerous outfalls for stormwater discharge. The sanitary sewer system serves 84% of households in the watershed. JEA reported only one sanitary sewer overflow in the watershed, which occurred in 2002 and potentially impacted surface waters. WSEA estimates that there are 177 on-site sewage treatment and disposal systems (septic systems) in use. Annual Progress Reports for this BMAP were published in 2011 (**DEP 2011c**), 2012 (**DEP 2013i**), and 2013 (**DEP 2013i**); they list repairs, inspections, evaluations, and other improvements conducted by JEA, the Duval County Health Department, COJ, and FDOT.

In the most recent draft verified impaired list (**DEP 2015b**) Greenfield Creek has been identified as being impaired for mercury. Once evaluated it may be added to the statewide mercury TMDL already in place (**DEP 2013a**).

Table 2.17 Water Quality Data for Greenfield Creek

Parameter	Water Quality Criteria (FW)	Concentration			Samples	Sampling Period
		Low	Average	High		
Dissolved Oxygen (mg/L)	34% sat. (~3.0)	2.30	6.06	13.71	131	1999 - 2012
Total Nitrogen (mg/L)	<1.54	0.71	1.33	3.97	21	2007
Total Phosphorus (mg/L)	<0.12	0.04	0.10	1.00	21	2007
Chlorophyll-a (µg/L)	<20	0.43	14.16	71.00	21	2007
Arsenic (µg/L)	≤50	No valid data available				
Cadmium (µg/L)	≤0.3	No valid data available				
Copper (µg/L)	≤9.3	No valid data available				
Lead (µg/L)	≤3.2	No valid data available				
Nickel (µg/L)	≤52	No valid data available				
Silver (µg/L)	≤0.07	No valid data available				
Zinc (µg/L)	≤120	No valid data available				
Fecal Coliform (log #/100 mL)	<2.6	0.60	2.33	4.02	105	1999 - 2012
Turbidity (NTU)	<29	0.85	10.46	45.0	21	2007

Note: Hardness-dependent freshwater criteria for cadmium, copper, lead, nickel, and zinc were generated based on a hardness concentration of 100 mg/L. FW=freshwater.

2.7.15. *Hogan Creek*

2.7.15.1. About Hogan Creek

- Downtown Jacksonville
- Primary Land Use: Residential
- Current TMDL reports: Fecal Coliform with BMAP (2009)
- Verified Impaired 2014 (draft): None
- WBID Area: 3.4 sq. mi.
- Beneficial Use: Class III F (Recreational – Freshwater)

Figure 2.46 The Hogan Creek Tributary (WBID 2252)

2.7.15.2. Data sources

Result data were downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010c**) in the Hogan Creek WBID 2252 (**DEP 2014f**) shown above. The filtered dataset was used to generate Table 2.13.

2.7.15.3. Discussion

Water quality data for Hogan Creek are shown in Table 2.18. Average phosphorus levels were higher than the recently updated WQC (**EPA 2010a**). Average total nitrogen and chlorophyll-a concentrations were within acceptable limits. *(Note: the datasets for these parameters are relatively small in comparison to other parts of the basin).* As the average level of dissolved oxygen is below the WQC, Hogan Creek has been identified as being impaired for this parameter.

The fecal coliform level, averaged over all the stations in Hogan Creek, is just below the critical level of 2.6, which is the logarithm of the state maximum of 400 colony-forming-units (cfu) per 100 mL. However, a TMDL for fecal coliform in Hogan Creek was finalized in 2006 (**Wainwright 2006b**). (*Note: the data analysis in the TMDL is based on different criteria than that used in this report*). Subsequently, a BMAP for Hogan Creek was legally adopted in December 2009 (**DEP 2009d**).

Annual Progress Reports for this BMAP were issued in 2011 (**DEP 2011b**), 2012 (**DEP 2012**), and 2013 (**DEP 2013h**); they list repairs, inspections, evaluations, and other improvements conducted by JEA, the Duval County Health Department, COJ, and FDOT.

Table 2.18 Water Quality Data for Hogan Creek

Parameter	Water Quality Criteria (FW)	Concentration			Samples	Sampling Period
		Low	Average	High		
Dissolved Oxygen (mg/L)	34% sat. (~3.0)	0.40	4.71	10.60	240	1999 - 2012
Total Nitrogen (mg/L)	<1.54	0.67	1.02	1.30	9	2000 - 2007
Total Phosphorus (mg/L)	<0.12	0.07	0.12	0.19	9	2000 - 2007
Chlorophyll-a (µg/L)	<20	0.60	13.55	26.00	6	2000 - 2007
Arsenic (µg/L)	≤50	0.56	1.10	2.10	5	2007
Cadmium (µg/L)	≤0.3	0.03	6.01	25.00	6	2001 - 2007
Copper (µg/L)	≤9.3	1.40	5.04	11.60	6	2001 - 2007
Lead (µg/L)	≤3.2	1.50	6.16	23.00	6	2001 - 2007
Nickel (µg/L)	≤52	0.53	0.98	2.00	6	2001 - 2007
Silver (µg/L)	≤0.07	0.01	0.14	0.75	6	2001 - 2007
Zinc (µg/L)	≤120	7.70	14.90	28.00	6	2001 - 2007
Fecal Coliform (log #/100 mL)	<2.6	-0.30	3.11	5.20	230	1999 - 2012
Turbidity (NTU)	<29	3.90	7.13	18.00	23	2000 - 2007

Note: Hardness-dependent freshwater criteria for cadmium, copper, lead, nickel, and zinc were generated based on a hardness concentration of 100 mg/L. FW=freshwater.

2.7.16. *Intracoastal Waterway*

2.7.16.1. About the Intracoastal Waterway

- Near the mouth of the St. Johns River
- Primary Land Use: Marsh/Wetland
- Current TMDL reports: Mercury
- Verified Impaired 2014 (draft): Fecal Coliform (low), Iron (med)
- WBID Area: 23.9 sq. mi.
- Beneficial Use: Class III M (Recreational – Marine)

Figure 2.47 The Intracoastal Waterway Tributary (WBID 2205C)

2.7.16.2. Data sources

Result data were downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010c**) in the Intracoastal Waterway (ICW) WBID 2205C (**DEP 2014f**) shown above. The filtered dataset was used to generate Table 2.14.

2.7.16.3. Discussion

Water quality data for the ICW are shown in Table 2.19. All parameters listed are within normal limits except for slightly elevated copper, phosphorus and chlorophyll-a. Based on this data the ICW is relatively healthy and does not provide a significant nutrient load to the St. Johns River. The Intracoastal Waterway was identified as being impaired for mercury, based on elevated levels of mercury in fish tissue, which is addressed by the statewide mercury TMDL (**DEP 2013a**).

Table 2.19 Water Quality Data for the Intracoastal Waterway

Parameter	Water Quality Criteria (SW)	Concentration			Samples	Sampling Period
		Low	Average	High		
Dissolved Oxygen (mg/L)	≥4.0	0.31	6.31	11.05	259	1999 - 2012
Total Nitrogen (mg/L)	<1.54	0.10	0.78	4.48	78	2007 - 2012
Total Phosphorus (mg/L)	<0.12	0.02	0.09	0.28	128	2000 - 2012
Chlorophyll-a (µg/L)	<11	0.43	4.69	23.00	79	2000 - 2012
Arsenic (µg/L)	≤50	1.50	2.45	3.30	24	2007
Cadmium (µg/L)	≤8.8	0.03	0.08	0.25	24	2007
Copper (µg/L)	≤3.7	1.00	2.60	8.00	24	2007
Lead (µg/L)	≤8.5	0.30	0.60	1.20	24	2007
Nickel (µg/L)	≤8.3	0.38	0.65	2.10	24	2007
Silver (µg/L)	≤0.92	0.04	0.05	0.13	24	2007
Zinc (µg/L)	≤86	7.50	12.83	69.00	24	2007
Fecal Coliform (log #/100 mL)	<2.6	0.48	2.41	4.59	79	1999 - 2012
Turbidity (NTU)	<29	1.80	6.87	23.50	73	2000 - 2010

Note: Hardness-dependent freshwater criteria for cadmium, copper, lead, nickel, and zinc were generated based on a hardness concentration of 100 mg/L. FW=freshwater; SW=saltwater(marine).

2.7.17. Julington Creek

2.7.17.1. <u>About Julington Creek</u>

- East of the St. Johns River at the I-95/I-295/9A intersection
- Primary Land Use: Marsh/Wetland
- Current TMDL reports: Fecal Coliform
- Verified Impaired 2014 (draft): DO (high), Iron (med)
- WBID Area: 20.4 sq. mi.
- Beneficial Use: Class III F (Recreational – Freshwater)

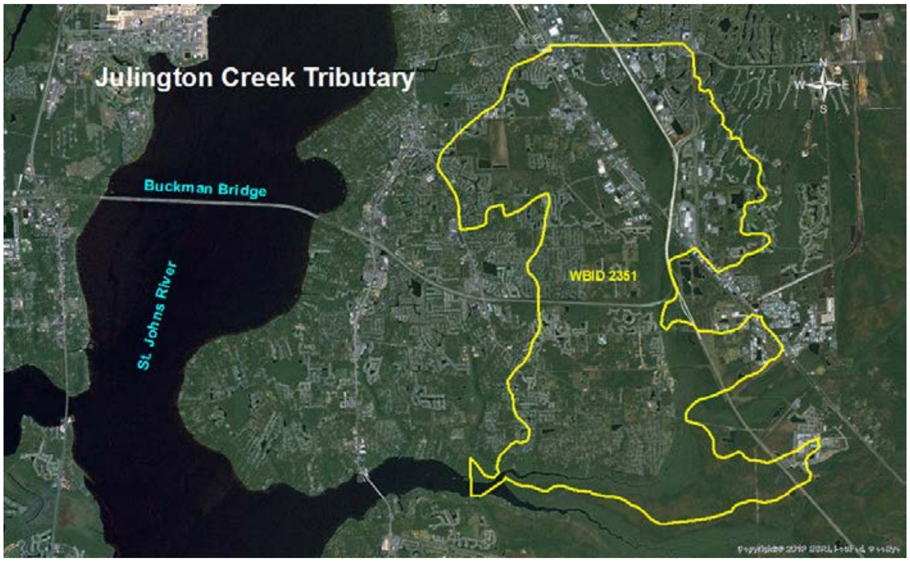


Figure 2.48 The Julington Creek Tributary (WBID 2351)

2.7.17.2. <u>Data sources</u>

Result data was downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010c**) in Julington Creek WBID 2351 (**DEP 2014f**) shown above. The filtered dataset was used to generate Table 2.20.

2.7.17.3. <u>Discussion</u>

Water quality data for Julington Creek are shown in Table 2.20. The fecal coliform level, averaged over all the stations in Julington Creek, is above the critical level of 2.6, which is the logarithm of the state maximum of 400 colony-forming-units (cfu) per 100 mL. Thus, a TMDL for fecal coliform was published in 2009 (**Rhew 2009a**). (*Note: the data analysis in the TMDL is based on different criteria than that used in this report*). Julington Creek is also an area in which relatively high ammonia levels have been measured.

Table 2.20 Water Quality Data for Julington Creek

Parameter	Water Quality Criteria (FW)	Concentration			Samples	Sampling Period
		Low	Average	High		
Dissolved Oxygen (mg/L)	34% sat. (~3.0)	0.49	5.32	11.96	241	1999 - 2012
Total Nitrogen (mg/L)	<1.54	0.49	1.09	2.22	75	1999 - 2012
Total Phosphorus (mg/L)	<0.12	0.00	0.07	0.21	123	1999 - 2012
Chlorophyll-a (µg/L)	<20	0.10	1.20	5.59	38	2002 - 2012
Arsenic (µg/L)	≤50	0.04	1.09	2.80	24	2004 - 2009
Cadmium (µg/L)	≤0.3	0.00	0.11	1.20	40	2004 - 2009
Copper (µg/L)	≤9.3	0.17	2.57	10.53	56	2004 - 2009
Lead (µg/L)	≤3.2	0.00	1.02	14.00	35	2004 - 2008
Nickel (µg/L)	≤52	0.00	0.57	7.00	48	2004 - 2009
Silver (µg/L)	≤0.07	0.00	0.15	0.36	18	2004 - 2009
Zinc (µg/L)	≤120	0.10	5.33	21.48	59	2004 - 2009
Fecal Coliform (log #/100 mL)	<2.6	1.00	2.31	3.78	180	1999 - 2012
Turbidity (NTU)	<29	0.60	7.05	24.40	65	1999 - 2012

Note: Hardness-dependent freshwater criteria for cadmium, copper, lead, nickel, and zinc were generated based on a hardness concentration of 100 mg/L. FW=freshwater.

2.7.18. McCoy Creek

2.7.18.1. <u>About McCoy Creek</u>

- West of the St. Johns River Downtown
- Primary Land Use: Residential
- Current TMDL reports: Fecal Coliform
- Verified Impaired 2014 (draft): None
- WBID Area: 5.34 sq. mi.
- Beneficial Use: Class III F (Recreational – Freshwater)

Figure 2.49 The McCoy Creek Tributary (WBID 2257)

2.7.18.2. <u>Data sources</u>

Result data was downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010c**) in McCoy Creek WBID 2257 (**DEP 2014f**) shown above. The filtered dataset was used to generate Table 2.21.

2.7.18.3. <u>Discussion</u>

Water quality data for McCoy Creek are shown in Table 2.21. The fecal coliform level, averaged over all the stations in McCoy Creek, is above the critical level of 2.6, which is the logarithm of the state maximum of 400 colony-forming-units (cfu) per 100 mL. Thus, a TMDL for fecal coliform was published in 2009 (**Rich-Zeisler and Kingon 2009**). (*Note: the data analysis in the TMDL is based on different criteria than that used in this report*). Subsequently, a BMAP for McCoy Creek was legally adopted in 2010 (**DEP 2010b**). Annual Progress Reports for this BMAP were published in 2011 (**DEP 2011c**), 2012 (**DEP 2013i**), and 2013 (**DEP 2013i**); they list repairs, inspections, evaluations, and other improvements conducted by JEA, the Duval County Health Department, COJ, and FDOT.

Average dissolved oxygen (DO) levels are below the WQC but are above the SSAC of 4.0 mg/L for DO in the mainstem and tributaries (**DEP 2014h**).

Table 2.21 Water Quality Data for McCoy Creek

Parameter	Water Quality Criteria (FW)	Concentration			Samples	Sampling Period
		Low	Average	High		
Dissolved Oxygen (mg/L)	34% sat. (~3.0)	0.68	4.18	14.91	257	1999 - 2013
Total Nitrogen (mg/L)	<1.54	0.19	0.87	1.61	61	2000 - 2013
Total Phosphorus (mg/L)	<0.12	0.04	0.17	0.42	84	2000 - 2013
Chlorophyll-a (µg/L)	<20	0.28	2.61	21.00	22	2000 - 2013
Arsenic (µg/L)	≤50	0.002	2.96	8.38	28	2000 - 2008
Cadmium (µg/L)	≤0.3	0.002	1.59	25.00	70	2000 - 2008
Copper (µg/L)	≤9.3	0.02	3.96	50.00	79	2000 - 2008
Lead (µg/L)	≤3.2	0.00	7.74	50.00	87	2000 - 2008
Nickel (µg/L)	≤52	0.00	4.15	50.00	79	2000 - 2008
Silver (µg/L)	≤0.07	0.00	0.40	5.00	28	2000 - 2008
Zinc (µg/L)	≤120	0.04	20.15	317.62	82	2000 - 2008
Fecal Coliform (log #/100 mL)	<2.6	0.00	2.87	5.18	224	1999 - 2012
Turbidity (NTU)	<29	0.00	8.61	71.20	126	2000 - 2013

Note: Hardness-dependent freshwater criteria for cadmium, copper, lead, nickel, and zinc were generated based on a hardness concentration of 100 mg/L. FW=freshwater.

2.7.19. Mill Creek

2.7.19.1. About Mill Creek

- East of the St. Johns River feeding into Sixmile Creek
- Primary Land Use: Wetlands/forest
- Current TMDL reports: Fecal Coliform, DO/Nutrient
- Verified Impaired 2014 (draft): Iron (high)
- WBID Area: 11.6 sq. mi.
- Beneficial Use: Class III F (Recreational – Freshwater)

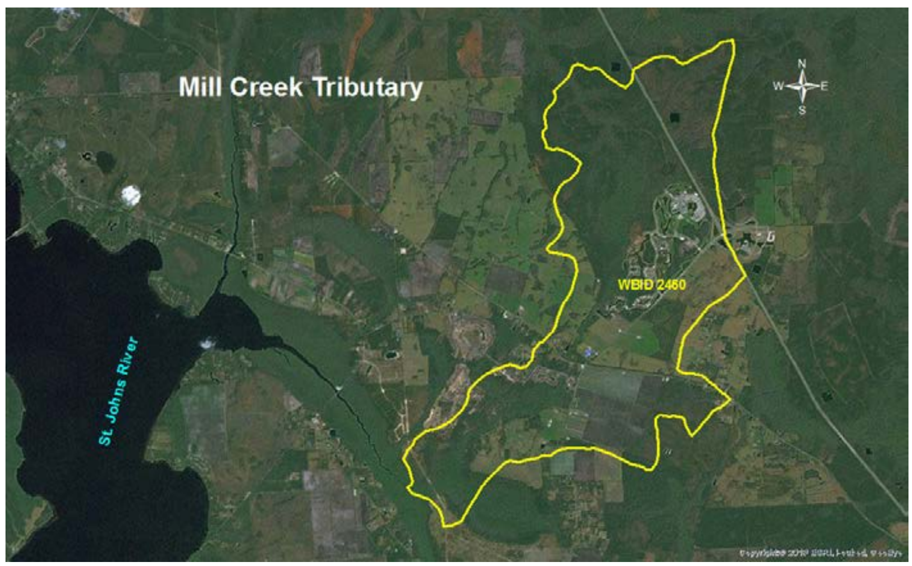


Figure 2.50 The Mill Creek Tributary (WBID 2460)

2.7.19.2. Data sources

Result data was downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010c**) in Mill Creek WBID 2460 (**DEP 2014f**) shown above. The filtered dataset was used to generate Table 2.22.

2.7.19.3. Discussion

Water quality data for Mill Creek are shown in Table 2.22. The fecal coliform level, averaged over all the stations in Mill Creek, is above the critical level of 2.6, which is the logarithm of the state maximum of 400 colony-forming-units (cfu) per 100 mL. Thus, a TMDL for fecal coliform was published in 2009 (**Rhew 2009b**). (*Note: the data analysis in the TMDL is based on different criteria than that used in this report*). In addition, Mill Creek has been identified as impaired for dissolved oxygen and associate nutrients and a TMDL addressing this was published in 2010 (**Magley 2010**). Iron has been added in the recent draft verified impaired list (**DEP 2015b**) for Mill Creek and is potentially a natural condition, common in Florida blackwater streams such as this.

Table 2.22 Water Quality Data for Mill Creek

Parameter	Water Quality Criteria (FW)	Concentration			Samples	Sampling Period
		Low	Average	High		
Dissolved Oxygen (mg/L)	34% sat. (~3.0)	2.38	5.42	9.56	115	2002 - 2013
Total Nitrogen (mg/L)	<1.54	0.21	1.11	3.03	86	2002 - 2013
Total Phosphorus (mg/L)	<0.12	0.03	0.14	0.77	139	2002 - 2013
Chlorophyll-a (µg/L)	<20	0.00	7.27	50.0	67	2002 - 2013
Arsenic (µg/L)	≤50	0.03	1.68	4.64	58	2005 - 2009
Cadmium (µg/L)	≤0.3	0.000	0.05	0.19	56	2005 - 2009
Copper (µg/L)	≤9.3	0.55	2.35	7.51	74	2005 - 2009
Lead (µg/L)	≤3.2	0.10	0.58	1.52	49	2005 - 2009
Nickel (µg/L)	≤52	0.09	0.60	3.74	44	2005 - 2008
Silver (µg/L)	≤0.07	0.00	0.08	0.40	48	2006 - 2009
Zinc (µg/L)	≤120	0.87	4.47	32.2	73	2005 - 2009
Fecal Coliform (log #/100 mL)	<2.6	1.30	2.28	3.90	45	2002 - 2008
Turbidity (NTU)	<29	1.90	8.73	130	66	2002 - 2012

Note: Hardness-dependent freshwater criteria for cadmium, copper, lead, nickel, and zinc were generated based on a hardness concentration of 100 mg/L. FW=freshwater.

2.7.20. Moncrief Creek

2.7.20.1. <u>About Moncrief Creek</u>

- North of downtown Jacksonville
- Primary Land Use: Residential
- Current TMDL reports: Fecal/Total Coliform with BMAP (2010), Mercury
- Verified Impaired 2014 (draft): Copper (high), Iron (high), Lead (med), Chlorophyll-a (high)
- WBID Area: 5.9 sq. mi.
- Beneficial Use: Class III F (Recreational – Marine)

Figure 2.51 The Moncrief Creek Tributary (WBID 2228)

2.7.20.2. <u>Data sources</u>

Result data were downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010c**) in the Moncrief Creek WBID 2228 (**DEP 2014f**) shown above. The filtered dataset was used to generate Table 2.23.

2.7.20.3. <u>Discussion</u>

Water quality data for Moncrief Creek are shown in Table 2.23. Average phosphorus levels were higher than the recently updated WQC (**EPA 2010a**). Average total nitrogen and dissolved oxygen concentrations were within acceptable limits, and chlorophyll-a concentrations were only slightly elevated. Average copper concentrations were elevated relative to other tributaries and some concentrations were well above WQC.

The fecal coliform level, averaged over all the stations in Moncrief Creek, is below the critical level of 2.6, which is the logarithm of the state maximum of 400 colony-forming-units (cfu) per 100 mL. However, there is some variation in the levels depending on the location. Analysis by station is shown in Figure 2.52, going from downstream to upstream. The furthest downstream station at which fecal coliform data are available is station 20030114, near the intersection of I-95 and

Norwood Avenue, and the furthest upstream station is station 20030897, near Kings Road. Beginning at station TR316 the average level exceeds the state maximum at every station. This is an old neighborhood that has been populated for many decades and contains both residential and light industrial development. South of the Martin Luther King Jr. Parkway, the average level is lower than the state maximum.

A TMDL report for fecal coliform was published for Moncrief Creek in 2006 (**Wainwright 2006c**). (*Note: the data analysis in the TMDL is based on different criteria than that used in this report*). Subsequently, a BMAP for Moncrief Creek (**DEP 2010b**) was released in August 2010. It describes sources of fecal coliform in the watershed, and completed and ongoing activities conducted by state and local agencies that are anticipated to reduce fecal coliform loading in the tributary. The Moncrief Creek watershed contains four permitted point sources for industrial wastewater, as well as numerous outfalls for stormwater discharge. A sewer system serves 90% of households in the watershed. Between 2002 and 2006, JEA reported 17 sanitary sewer overflows in the watershed, five of which potentially impacted surface waters. WSEA estimates that there are 989 on-site sewage treatment and disposal systems (septic systems) in use. JEA has been conducting two large projects to replace or rehabilitate failing or leaking infrastructure in this watershed. COJ has constructed two wet detention projects and has worked with WSEA to add new sewer lines in order to eliminate 210 septic systems. Annual Progress Reports for this BMAP were published in 2011 (**DEP 2011c**), 2012 (**DEP 2013i**), and 2013 (**DEP 2013i**); they list repairs, inspections, evaluations, and other improvements conducted by JEA, the Duval County Health Department, COJ, and FDOT.

Moncrief Creek has been identified as impaired for copper, iron, and lead (**DEP 2014c**). It was identified as being impaired for mercury, based on elevated levels of mercury in fish tissue, however this is being delisted (**DEP 2015c**) as it has been addressed by the statewide mercury TMDL (**DEP 2013a**).

Table 2.23 Water Quality Data for Moncrief Creek

Parameter	Water Quality Criteria (SW)	Concentration			Samples	Sampling Period
		Low	Average	High		
Dissolved Oxygen (mg/L)	34% sat. (~3.0)	0.41	6.06	15.08	407	1998 - 2014
Total Nitrogen (mg/L)	<1.54	0.08	0.97	5.76	117	1998 - 2014
Total Phosphorus (mg/L)	<0.12	0.0001	0.12	1.31	150	1998 - 2014
Chlorophyll-a (µg/L)	<20	0.50	12.06	140.3	85	1998 - 2014
Arsenic (µg/L)	≤50	0.48	8.76	124.0	80	1998 - 2014
Cadmium (µg/L)	≤0.3	0.003	1.20	50.00	97	1998 - 2014
Copper (µg/L)	≤9.3	0.02	4.69	50.00	135	1998 - 2014
Lead (µg/L)	≤3.2	0.00	6.32	50.00	124	1998 - 2014
Nickel (µg/L)	≤52	0.00	4.55	50.00	117	1998 - 2014
Silver (µg/L)	≤0.07	0.00	0.63	5.00	26	2000 - 2014
Zinc (µg/L)	≤120	0.04	13.27	53.06	142	1998 - 2014
Fecal Coliform (log #/100 mL)	<2.6	0.65	2.87	4.98	352	1999 - 2014
Turbidity (NTU)	<29	0.00	8.90	39.90	196	1998 - 2014

Note: Hardness-dependent freshwater criteria for cadmium, copper, lead, nickel, and zinc were generated based on a hardness concentration of 100 mg/L. SW=saltwater (marine).

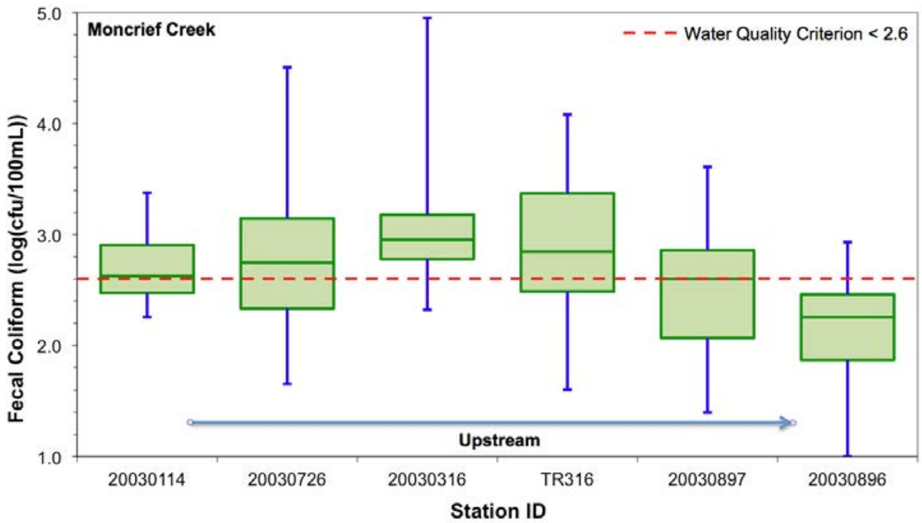


Figure 2.52 Fecal coliform in Moncrief Creek from downstream to upstream. Data are presented as the log of the number of fecal coliform bacteria per 100 mL; the maximum, mean, and minimum values at each station are shown.

2.7.21. Open Creek

2.7.21.1. <u>About Open Creek</u>

- West of the Intracoastal Waterway
- Primary Land Use: Residential
- Current TMDL reports:
  Fecal Coliform with BMAP (2009)
- Verified Impaired 2014 (draft):
  Mercury (eval)
- WBID Area: 6.5 sq. mi.
- Beneficial Use: Class III M & F
  (Marine - 2299A, Freshwater - 2299B)

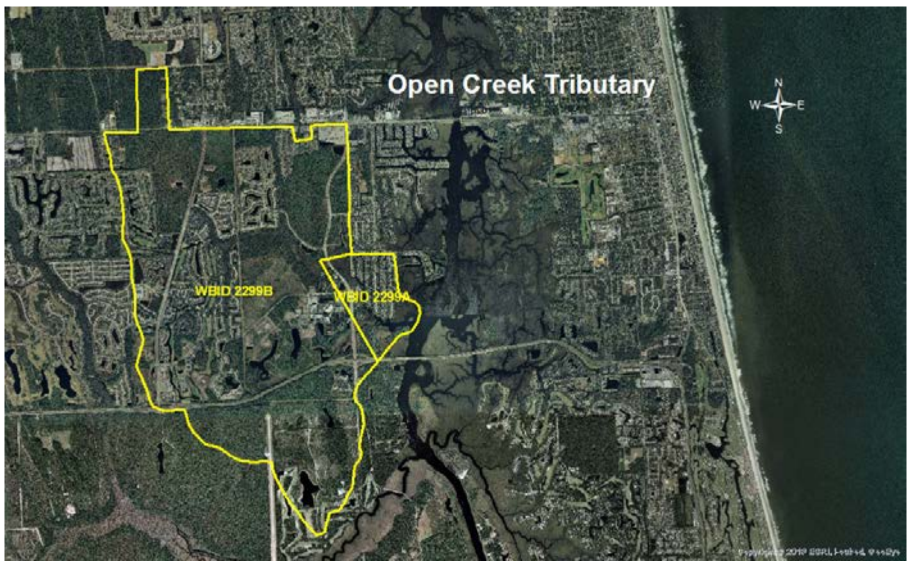


Figure 2.53 Open Creek (WBID 2299A/B)

2.7.21.2. <u>Data sources</u>

Result data were downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010c**) in Open Creek WBID 2299A/B (**DEP 2014f**) shown above. The filtered dataset was used to generate Table 2.24.

2.7.21.3. <u>Discussion</u>

Water quality data for Open Creek are shown in Table 2.24. Average nutrient levels (total nitrogen, total phosphorus, and dissolved oxygen) and turbidity were in the normal range. *(Note: the datasets for these parameters are relatively small in comparison to other parts of the basin).*

The fecal coliform level, averaged over all the stations in Open Creek, is elevated but below the critical level of 2.6, which is the logarithm of the state maximum of 400 colony-forming-units (cfu) per 100 mL. However, there is some variation in the levels dependent on the location. Figure 2.54 shows fecal coliform levels at various stations on Open Creek. These do not go in a downstream-to-upstream direction because these points lie on different streams that are tributaries to Open Creek. All are above the water quality criterion except 20030848, which is near the intersection of Hodges Boulevard and Danforth Road.

A TMDL report (**Wainwright and Hallas 2009b**) was released in 2009 to address fecal coliform. (*Note: the data analysis in the TMDL is based on different criteria than that used in this report*). Subsequently, a BMAP to address this issue was legally adopted (**DEP 2009d**). Annual Progress Reports for this BMAP were issued in 2010 (**DEP 2011b**), 2011 (**DEP 2012**), and 2012 (**DEP 2013h**); they list repairs, inspections, evaluations, and other improvements conducted by JEA, the Duval County Health Department, COJ, and FDOT.

In the most recent draft verified impaired list (**DEP 2015b**) Open Creek has been identified as being impaired for mercury. Once evaluated it may be added to the statewide mercury TMDL already in place (**DEP 2013a**).

Table 2.24 Water Quality Data for Open Creek

Parameter	Water Quality Criteria	Concentration			Samples	Sampling Period
		Low	Average	High		
Dissolved Oxygen (mg/L)	34% sat. FW ≥4.0 SW	0.80	5.75	12.00	211	1999 - 2014
Total Nitrogen (mg/L)	<1.54	0.43	0.83	1.78	35	2007 - 2012
Total Phosphorus (mg/L)	<0.12	0.01	0.04	0.28	35	2007 - 2012
Chlorophyll-a (μg/L)	<20 FW <11 SW	0.28	3.17	11.00	35	2007 - 2012
Arsenic (μg/L)	≤50 FW ≤50 SW	No valid data available				
Cadmium (μg/L)	≤0.3 FW ≤8.8 SW	No valid data available				
Copper (μg/L)	≤9.3 FW ≤3.7 SW	No valid data available				
Lead (μg/L)	≤3.2 FW ≤8.5 SW	No valid data available				
Nickel (μg/L)	≤52 FW ≤8.3 SW	No valid data available				
Silver (μg/L)	≤0.07 FW ≤0.92 SW	No valid data available				
Zinc (μg/L)	≤120 FW ≤86 SW	No valid data available				
Fecal Coliform (log #/100 mL)	<2.6	0.30	2.77	4.11	194	1999 - 2014
Turbidity (NTU)	<29	1.50	4.83	12.30	47	2007 - 2013

Note: Hardness-dependent freshwater criteria for cadmium, copper, lead, nickel, and zinc were generated based on a hardness concentration of 100 mg/L. FW=freshwater; SW=saltwater(marine).

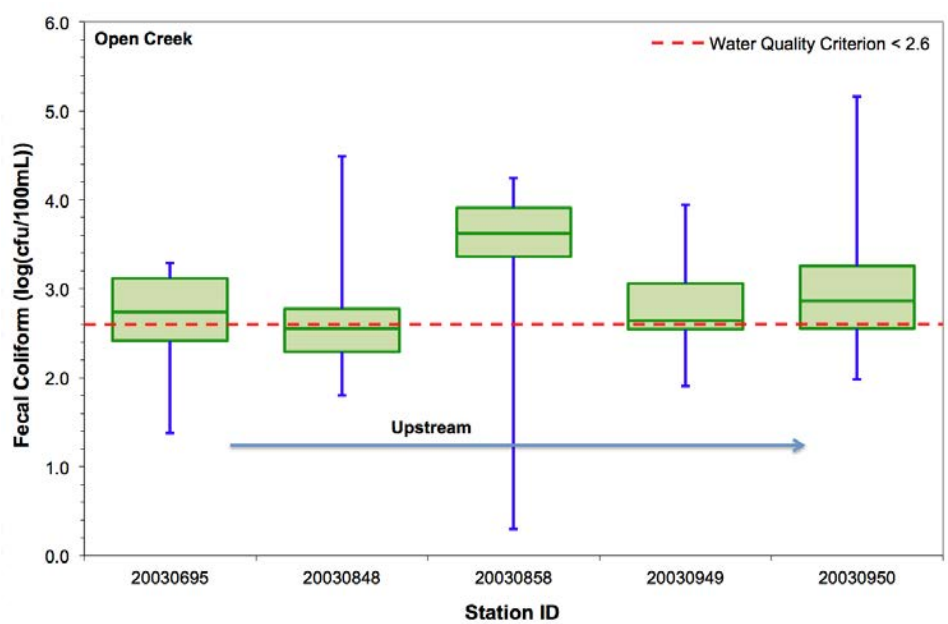


Figure 2.54 Fecal coliform in Open Creek from downstream to upstream. Data are presented as the log of the number of fecal coliform bacteria per 100 mL; the maximum, mean, and minimum values at each station are shown.

2.7.22. *Ortega River*

2.7.22.1. About the Ortega River

- West of NAS Jacksonville
- Primary Land Use: Residential
- Current TMDL reports:
  Fecal Coliform – 2213P1
  DO/Nutrient – 2213P1 (draft)
- Verified Impaired 2014 (draft):
  Fecal Coliform (2249A med)
- WBID Area: 29.0 sq. mi.
- Beneficial Use: Class III F
  (Recreational – Freshwater)

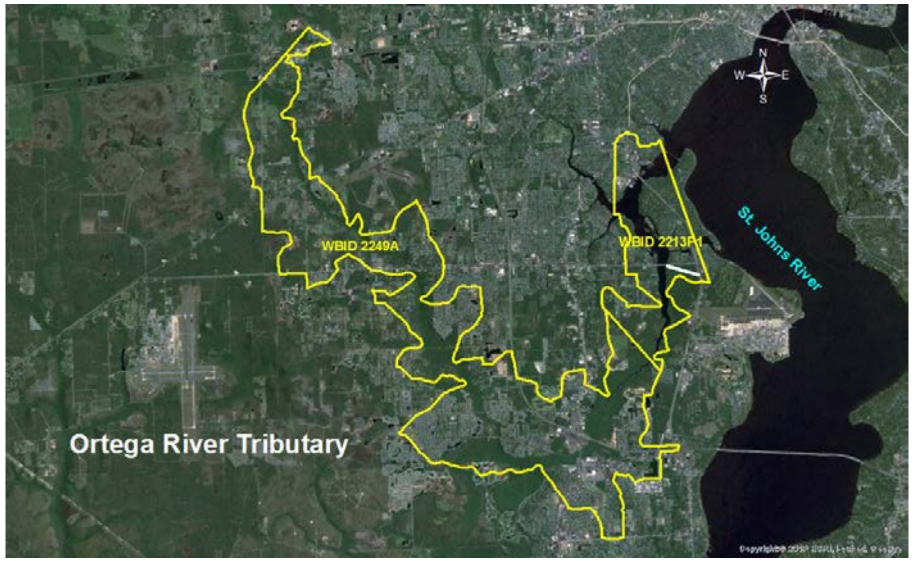


Figure 2.55 The Ortega River Tributary (WBID 2213P1 and 2249A)

2.7.22.2. Data sources

Result data were downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010c**) in the Ortega River WBID 2213P1 and 2249A (**DEP 2014f**) shown above. The filtered dataset was used to generate Table 2.25.

2.7.22.3. Discussion

Water quality data for the Ortega River are shown in Table 2.25. Average total nitrogen, total phosphorus, dissolved oxygen and chlorophyll-a concentrations were within acceptable limits. The fecal coliform level, averaged over all the sampling sites in the Ortega River, is below the critical level of 2.6, which is the logarithm of the state maximum of 400 colony-forming-units per 100 mL. The average at each individual sampling site also falls below the critical level. However, this analysis brings together data from both WBIDs and if the data is separated by WBID, WBID 2213P1 (downstream) has a significantly higher fecal coliform level than WBID 2249A. As a consequence, a TMDL report for fecal coliform in WBID 2213P1 was published in 2009 (**Rhew 2009c**).

Table 2.25 Water Quality Data for the Ortega River

Parameter	Water Quality Criteria (FW)	Concentration			Samples	Sampling Period
		Low	Average	High		
Dissolved Oxygen (mg/L)	34% sat. (~3.0)	0.25	5.46	19.71	474	1998 - 2014
Total Nitrogen (mg/L)	<1.54	0.16	0.85	2.47	170	1998 - 2014
Total Phosphorus (mg/L)	<0.12	0.02	0.07	0.84	199	1998 - 2014
Chlorophyll-a (µg/L)	<20	0.00	2.35	64.00	105	1998 - 2014
Arsenic (µg/L)	≤50	0.001	2.73	46.80	67	1998 - 2014
Cadmium (µg/L)	≤0.3	0.000	0.88	50.00	89	1998 - 2014
Copper (µg/L)	≤9.3	0.00	2.41	50.00	128	1998 - 2014
Lead (µg/L)	≤3.2	0.00	4.17	50.00	112	1998 - 2014
Nickel (µg/L)	≤52	0.00	2.87	50.00	117	1998 - 2014
Silver (µg/L)	≤0.07	0.00	0.17	1.24	27	2004 - 2014
Zinc (µg/L)	≤120	0.04	7.73	50.00	134	1998 - 2014
Fecal Coliform (log #/100 mL)	<2.6	-0.30	2.12	4.04	295	1999 - 2013
Turbidity (NTU)	<29	0.00	5.91	64.00	230	1998 - 2014

Note: Hardness-dependent freshwater criteria for cadmium, copper, lead, nickel, and zinc were generated based on a hardness concentration of 100 mg/L. FW=freshwater.

2.7.23. Peters Creek

2.7.23.1. About Peters Creek

- Flows into Black Creek
- Primary Land Use: Forest/agriculture
- Current TMDL reports: Lead, Fecal Coliform
- Verified Impaired 2014 (draft): None
- WBID Area: 20.5 sq. mi.
- Beneficial Use: Class III F (Recreational – Freshwater)

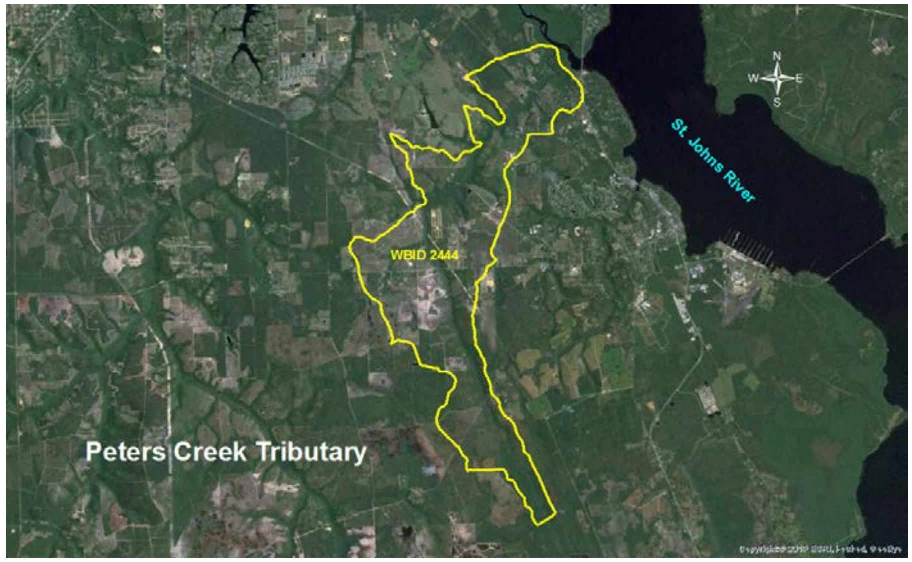


Figure 2.56 The Peters Creek Tributary (WBID 2444)

2.7.23.2. Data sources

Result data were downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010c**) in Peters Creek WBID 2444 (**DEP 2014f**) shown above. The filtered dataset was used to generate Table 2.26.

2.7.23.3. Discussion

Water quality data for Peters Creek are shown in Table 2.26. Average total nitrogen, total phosphorus, dissolved oxygen and chlorophyll-a concentrations were within acceptable limits. The fecal coliform level, averaged over all the sampling sites in the Peters Creek, is above the critical level of 2.6, which is the logarithm of the state maximum of 400 colony-forming-units per 100 mL. As a consequence a TMDL report was published in 2009 to address this impairment (**Rhew 2009d**). In addition, even though the mean concentration of lead is significantly lower than the freshwater water quality criteria, lead has been identified as impaired (high percentage of exceedances) in Peters Creek and a TMDL report was published in 2009 (**Lewis and Mandrup-Poulsen 2009**) to address this issue.

Table 2.26 Water Quality Data for Peters Creek

Parameter	Water Quality Criteria (FW)	Concentration			Samples	Sampling Period
		Low	Average	High		
Dissolved Oxygen (mg/L)	34% sat. (~3.0)	0.28	5.30	12.31	495	1997 - 2011
Total Nitrogen (mg/L)	<1.54	0.10	0.67	1.43	483	1997 - 2011
Total Phosphorus (mg/L)	<0.12	0.01	0.07	0.32	748	1997 - 2011
Chlorophyll-a (µg/L)	<20	0.00	3.31	27.68	243	1997 - 2011
Arsenic (µg/L)	≤50	0.00	1.26	6.77	188	1997 - 2011
Cadmium (µg/L)	≤0.3	0.00	0.11	1.65	287	1997 - 2010
Copper (µg/L)	≤9.3	0.00	1.00	112.02	413	1997 - 2011
Lead (µg/L)	≤3.2	0.00	0.72	4.13	378	1997 - 2011
Nickel (µg/L)	≤52	0.00	1.13	20.70	248	1997 - 2011
Silver	≤0.07	0.00	0.13	1.30	161	1997 - 2010
Zinc (µg/L)	≤120	0.29	4.50	31.37	462	1997 - 2011
Fecal Coliform (log #/100 mL)	<2.6	1.38	2.63	3.38	28	2004 - 2007
Turbidity (NTU)	<29	0.50	3.01	95.00	496	1997 - 2011

Note: Hardness-dependent freshwater criteria for cadmium, copper, lead, nickel, and zinc were generated based on a hardness concentration of 100 mg/L. FW=freshwater.

2.7.24. Pottsburg Creek

2.7.24.1. About Pottsburg Creek

- East of the St. Johns River at the Butler Blvd./I-95 interchange
- Primary Land Use: Residential
- Current TMDL reports: Fecal coliform with BMAP (2010)
- Verified Impaired 2014 (draft): None
- WBID Area: 9.1 sq. mi.
- Beneficial Use: Class III F (Recreational – Freshwater)

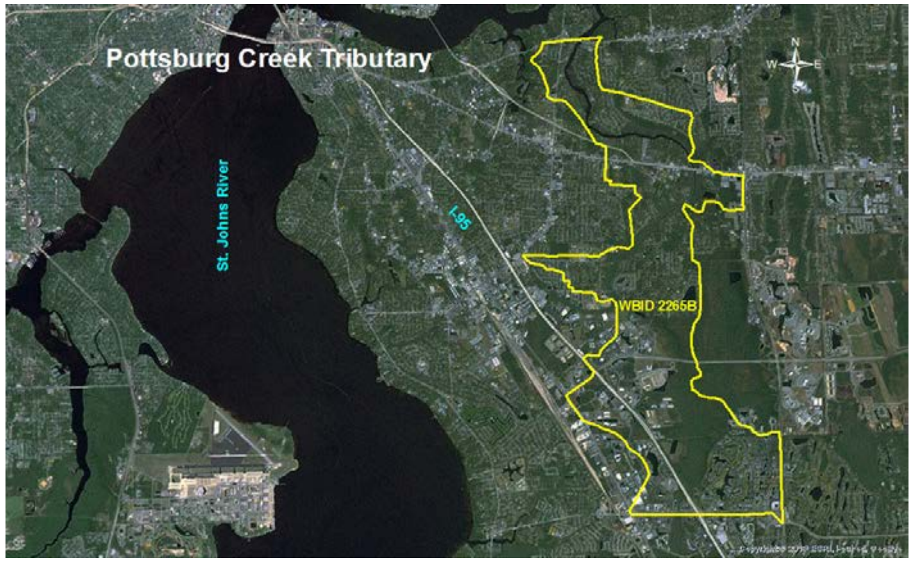


Figure 2.57 The Pottsburg Creek Tributary (WBID 2265B)

2.7.24.2. Data sources

Result data were downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010c**) in the Pottsburg Creek WBID 2265B (**DEP 2014f**) shown above. The filtered dataset was used to generate Table 2.27.

2.7.24.3. Discussion

Water quality data for Pottsburg Creek are shown in Table 2.27. Average phosphorus levels were higher than the recently updated WQC (**EPA 2010a**), however, average dissolved oxygen and chlorophyll-a were within limits. Fecal coliform data in Table 2.21 (1999-2012) indicates that the average is well above the WQC and fecal coliform levels in this residential tributary were identified as impaired in 2004. Consequently, a TMDL for fecal coliform was published (**Rhew 2009a**).

A BMAP for Pottsburg Creek (**DEP 2010b**) was legally adopted in August 2010. It describes sources of fecal coliform in the watershed, and completed and ongoing activities conducted by state and local agencies that are anticipated to reduce fecal coliform loading in the tributary. The Pottsburg Creek watershed contains one permitted point source for industrial wastewater, as well as numerous outfalls for stormwater discharge. A sewer system serves 33% of households in the watershed. Between 2001 and 2006, JEA reported 13 sanitary sewer overflows in the watershed, two of which potentially impacted surface waters. WSEA estimates that there are 1,585 on-site sewage treatment and disposal systems (septic systems) in use. COJ has constructed three wet detention projects and has worked with WSEA to add new sewer lines in order to eliminate 354 septic systems. Annual Progress Reports for this BMAP were published in 2011 (**DEP 2011c**), 2012 (**DEP 2013i**), and 2013 (**DEP 2013i**); they list repairs, inspections, evaluations, and other improvements conducted by JEA, the Duval County Health Department, COJ, and FDOT.

Table 2.27 Water Quality Data for Pottsburg Creek

Parameter	Water Quality Criteria (FW)	Concentration			Samples	Sampling Period
		Low	Average	High		
Dissolved Oxygen (mg/L)	34% sat. (~3.0)	0.34	5.38	10.53	196	1999 - 2013
Total Nitrogen (mg/L)	<1.54	0.34	0.94	1.83	88	1999 - 2013
Total Phosphorus (mg/L)	<0.12	0.00	0.14	0.43	101	1999 - 2013
Chlorophyll-a (µg/L)	<20	0.43	6.43	39.00	50	2002 - 2013
Arsenic (µg/L)	≤50	0.73	1.65	3.30	26	2005 - 2007
Cadmium (µg/L)	≤0.3	0.01	2.16	51.30	55	2002 - 2007
Copper (µg/L)	≤9.3	0.02	3.73	50.00	70	2002 - 2007
Lead (µg/L)	≤3.2	0.00	6.32	50.00	67	2002 - 2007
Nickel (µg/L)	≤52	0.00	4.52	50.00	70	2002 - 2007
Silver (µg/L)	≤0.07	0.01	0.03	0.04	22	2007
Zinc (µg/L)	≤120	0.04	7.16	50.00	70	2002 - 2007
Fecal Coliform (log #/100 mL)	<2.6	1.00	2.48	5.20	196	1999 - 2012
Turbidity (NTU)	<29	0.10	7.33	72.00	82	1999 - 2013

Note: Hardness-dependent freshwater criteria for cadmium, copper, lead, nickel, and zinc were generated based on a hardness concentration of 100 mg/L. FW=freshwater.

2.7.25. Ribault River

2.7.25.1. About the Ribault River

- Northwest of downtown Jacksonville
- Primary Land Use: Residential
- Current TMDL reports: Fecal Coliform
- Verified Impaired 2014 (draft): DO (med), Chlorophyll-a (med)
- WBID Area: 9.7 sq. mi.
- Beneficial Use: Class III F (Recreational – Freshwater)

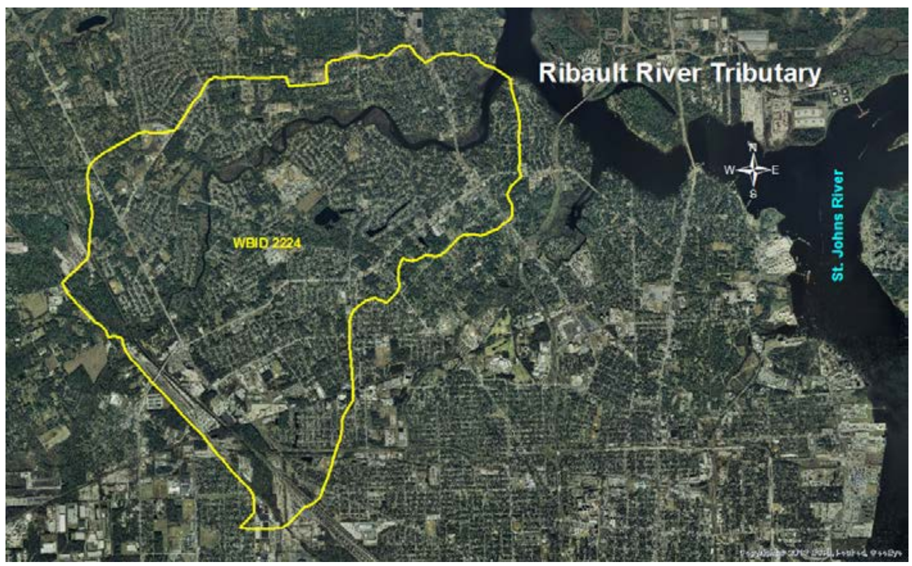


Figure 2.58 The Ribault River Tributary (WBID 2224)

2.7.25.2. Data sources

Result data were downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010c**) in the Ribault River WBID 2224 (**DEP 2014f**) shown above. The filtered dataset was used to generate Table 2.28.

2.7.25.3. Discussion

Water quality data for the Ribault River are shown in Table 2.28. The Ribault River is located in a highly residential area and consequently is a contributor to elevated levels of phosphorus found in the tributary. High levels of chlorophyll-a have also been measured and Ribault River has been designated impaired but no TMDL has been published at this time.

The fecal coliform level, averaged over all the sampling sites in the Ribault River, is elevated but below the critical level of 2.6, which is the logarithm of the state maximum of 400 colony-forming-units per 100 mL. However, a TMDL report for fecal coliform in the Ribault River was published in 2006 (**Wainwright 2006d**) and a BMAP is under development. (*Note: the data analysis in the TMDL is based on different criteria than that used in this report*).

Table 2.28 Water Quality Data for the Ribault River

Parameter	Water Quality Criteria (FW)	Concentration			Samples	Sampling Period
		Low	Average	High		
Dissolved Oxygen (mg/L)	34% sat. (~3.0)	0.35	5.52	12.83	196	1999 - 2012
Total Nitrogen (mg/L)	<1.54	0.79	1.25	1.89	29	2001 - 2007
Total Phosphorus (mg/L)	<0.12	0.08	0.25	0.41	28	2005 - 2007
Chlorophyll-a (µg/L)	<20	0.43	27.70	150	28	2005 - 2007
Arsenic (µg/L)	≤50	0.75	1.74	3.00	23	2006 - 2007
Cadmium (µg/L)	≤0.3	0.01	0.07	0.25	23	2006 - 2007
Copper (µg/L)	≤9.3	1.00	2.56	6.40	23	2006 - 2007
Lead (µg/L)	≤3.2	0.16	1.86	4.20	33	2004 - 2007
Nickel (µg/L)	≤52	0.50	1.22	2.60	23	2006 - 2007
Silver (µg/L)	≤0.07	0.01	0.04	0.13	23	2006 - 2007
Zinc (µg/L)	≤120	7.50	14.11	39.0	23	2006 - 2007
Fecal Coliform (log #/100 mL)	<2.6	-0.30	2.27	4.45	145	1999 - 2012
Turbidity (NTU)	<29	2.57	9.87	31.0	29	2001 - 2007

Note: Hardness-dependent freshwater criteria for cadmium, copper, lead, nickel, and zinc were generated based on a hardness concentration of 100 mg/L. FW=freshwater.

2.7.26. Rice Creek

2.7.26.1. About the Rice Creek

- West of Palatka
- Primary Land Use: Forested/Wetland
- Current TMDL reports: None
- Verified Impaired 2014 (draft): Dioxin (eval)
- WBID Area: 31.1 sq. mi.
- Beneficial Use: Class III F (Recreational – Freshwater)

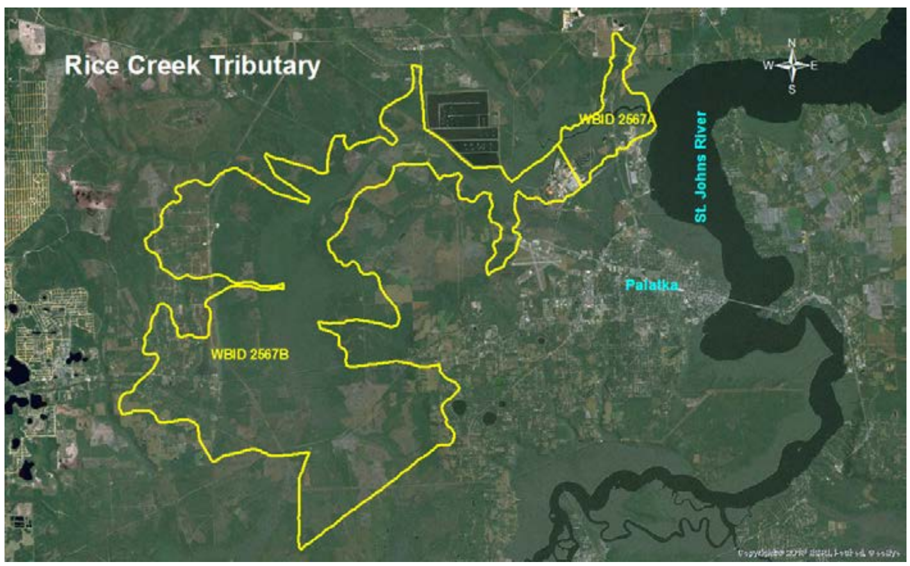


Figure 2.59 The Rice Creek Tributary (WBID 2567A/B)

2.7.26.2. Data sources

Result data were downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010c**) in the Rice Creek WBID 2567A/B (**DEP 2014f**) shown above. The filtered dataset was used to generate Table 2.29.

2.7.26.3. Discussion

Water quality data for Rice Creek are shown in Table 2.29. Rice Creek is predominantly surrounded by wetlands, forests including The Rice Creek Wildlife Management Area and a pulp mill (Georgia-Pacific). Dissolved oxygen and total nitrogen levels were below their WQC. Total phosphorus, chlorophyll-a and turbidity levels previously indicated as elevated are now within normal levels. Rice Creek has been identified as being impaired for Dioxin (**DEP 2014c**) and Georgia Pacific has instituted measures to reduce levels in its effluent and has stopped discharging to the river. A re-evaluation of the levels of Dioxin currently in Rice Creek is needed.

Table 2.29 Water Quality Data for the Rice Creek

Parameter	Water Quality Criteria (FW)	Concentration			Samples	Sampling Period
		Low	Average	High		
Dissolved Oxygen (mg/L)	34% sat. (~3.0)	0.36	5.90	11.42	745	1997 - 2014
Total Nitrogen (mg/L)	<1.54	0.20	1.20	5.77	353	1997 - 2014
Total Phosphorus (mg/L)	<0.12	0.004	0.08	0.56	533	1997 - 2014
Chlorophyll-a (µg/L)	<20	0.00	6.65	70.40	337	1997 - 2014
Arsenic (µg/L)	≤50	0.00	1.40	22.00	171	1997 - 2011
Cadmium (µg/L)	≤0.3	0.00	0.10	1.09	165	1997 - 2011
Copper (µg/L)	≤9.3	0.00	1.39	9.86	215	1997 - 2012
Lead (µg/L)	≤3.2	0.00	0.87	11.26	188	1997 - 2012
Nickel (µg/L)	≤52	0.00	3.95	21.30	212	1997 - 2012
Silver (µg/L)	≤0.07	0.00	0.23	5.00	112	1997 - 2011
Zinc (µg/L)	≤120	0.001	7.14	36.41	223	1997 - 2012
Fecal Coliform (log #/100 mL)	<2.6	1.15	2.03	3.36	139	2002 - 2014
Turbidity (NTU)	<29	0.00	7.31	400	356	1997 - 2014

Note: Hardness-dependent freshwater criteria for cadmium, copper, lead, nickel, and zinc were generated based on a hardness concentration of 100 mg/L. FW=freshwater.

2.7.27. *Sixmile Creek*

2.7.27.1. About the Sixmile Creek

- East of the St. Johns River in St. Johns County
- Primary Land Use: Forested/Wetland
- Current TMDL reports: None
- Verified Impaired 2014 (draft): None
- WBID Area: 59.5 sq. mi.
- Beneficial Use: Class III F (Recreational – Freshwater)

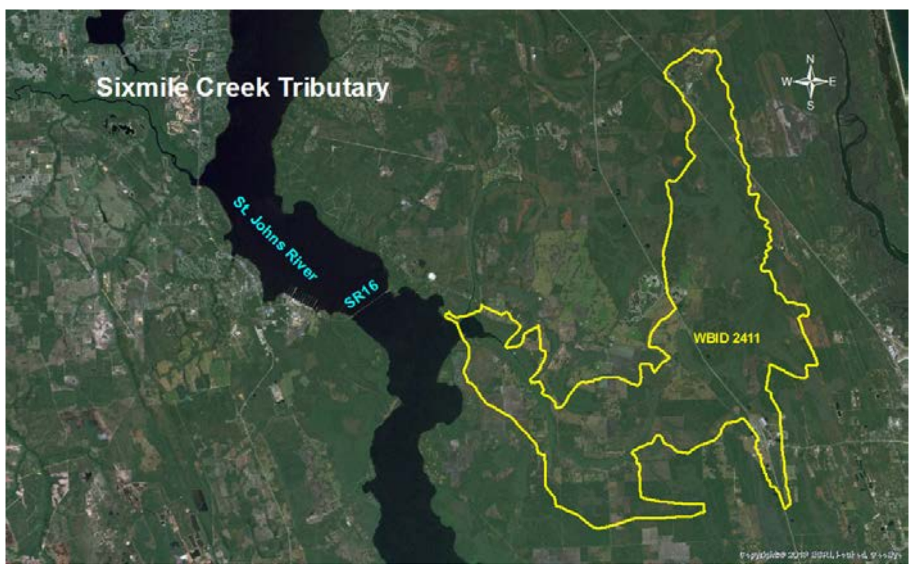


Figure 2.60 The Sixmile Creek Tributary (WBID 2411)

2.7.27.2. Data sources

Result data were downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010c**) in the Sixmile Creek WBID 2411 (**DEP 2014f**) shown above. The filtered dataset was used to generate Table 2.30.

2.7.27.3. Discussion

Water quality data for Sixmile Creek are shown in Table 2.30. Dissolved oxygen levels in Sixmile Creek are relatively low, compared to other tributaries (Figure 2.41); however, this is likely attributed to the wetland areas surrounding the creek and therefore it is not listed as impaired (**DEP 2009g**). Chlorophyll-a levels have exceeded WQC in the past but recent data have shown levels are decreasing, and now the average is below the water quality criteria (20 µg/L) for freshwater streams. Silver levels are elevated, yet this has not been identified as an impairment.

Table 2.30 Water Quality Data for the Sixmile Creek

Parameter	Water Quality Criteria (FW)	Concentration			Samples	Sampling Period
		Low	Average	High		
Dissolved Oxygen (mg/L)	34% sat. (~3.0)	0.58	4.81	10.82	205	1997 - 2014
Total Nitrogen (mg/L)	<1.54	0.52	1.04	1.86	172	1997 - 2014
Total Phosphorus (mg/L)	<0.12	0.009	0.09	0.67	355	1997 - 2014
Chlorophyll-a (μg/L)	<20	0.05	9.97	93.45	173	1997 - 2014
Arsenic (μg/L)	≤50	0.09	2.58	22.11	109	1997 - 2011
Cadmium (μg/L)	≤0.3	0.00	0.19	3.74	110	1997 - 2011
Copper (μg/L)	≤9.3	0.07	2.85	170.4	156	1997 - 2011
Lead (μg/L)	≤3.2	0.00	1.00	8.02	126	1997 - 2011
Nickel (μg/L)	≤52	0.00	3.40	98.70	125	1997 - 2011
Silver (μg/L)	≤0.07	0.00	0.29	3.41	95	1997 - 2011
Zinc (μg/L)	≤120	0.27	4.83	32.72	162	1997 - 2011
Fecal Coliform (log #/100 mL)	<2.6	2.18	2.18	2.18	1	2012
Turbidity (NTU)	<29	0.50	2.17	10.20	177	1997 - 2014

Note: Hardness-dependent freshwater criteria for cadmium, copper, lead, nickel, and zinc were generated based on a hardness concentration of 100 mg/L. FW=freshwater.

2.7.28. *Strawberry Creek*

2.7.28.1. About the Strawberry Creek

- Flows into the Arlington River
- Primary Land Use: Residential
- Current TMDL reports: Fecal Coliform
- Verified Impaired 2014 (draft): None
- WBID Area: 4.6 sq. mi.
- Beneficial Use: Class III F (Recreational – Freshwater)

Figure 2.61 The Strawberry Creek Tributary (WBID 2239)

2.7.28.2. Data sources

Result data were downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010c**) in the Strawberry Creek WBID 2239 (**DEP 2014f**) shown above. The filtered dataset was used to generate Table 2.31.

2.7.28.3. Discussion

Water quality data for the Strawberry Creek are shown in Table 2.31. Even though Strawberry Creek is located in a highly residential area levels of nutrients (nitrogen and phosphorus) and dissolved oxygen are at normal levels. This indicates that runoff from residential fertilization is not an issue at this time. The fecal coliform level, averaged over all the sampling sites in Strawberry Creek, is above the critical level of 2.6, which is the logarithm of the state maximum of 400 colony-forming-units per 100 mL. Thus, a TMDL report for fecal coliform in Strawberry Creek was published in 2009 (**Rhew 2009e**). (*Note: the data analysis in the TMDL is based on different criteria than that used in this report*).

Table 2.31 Water Quality Data for the Strawberry Creek

Parameter	Water Quality Criteria (FW)	Concentration Low	Concentration Average	Concentration High	Samples	Sampling Period
Dissolved Oxygen (mg/L)	34% sat. (~3.0)	1.65	5.77	12.01	188	1999 - 2012
Total Nitrogen (mg/L)	<1.54	0.52	1.08	1.56	42	1999 - 2012
Total Phosphorus (mg/L)	<0.12	0.02	0.06	0.28	42	1999 - 2012
Chlorophyll-a (µg/L)	<20	0.28	1.32	7.70	40	2002 - 2012
Arsenic (µg/L)	≤50	0.25	0.65	2.30	24	2007
Cadmium (µg/L)	≤0.3	0.01	0.03	0.14	24	2007
Copper (µg/L)	≤9.3	0.61	3.96	51.80	24	2007
Lead (µg/L)	≤3.2	0.23	2.13	25.00	24	2007
Nickel (µg/L)	≤52	0.34	0.97	6.50	24	2007
Silver (µg/L)	≤0.07	0.01	0.01	0.04	24	2007
Zinc (µg/L)	≤120	2.50	13.83	71.00	24	2007
Fecal Coliform (log #/100 mL)	<2.6	-0.30	2.60	4.62	147	1999 - 2012
Turbidity (NTU)	<29	1.10	6.67	37.00	32	1999 - 2007

Note: Hardness-dependent freshwater criteria for cadmium, copper, lead, nickel, and zinc were generated based on a hardness concentration of 100 mg/L. FW=freshwater.

2.7.29. *Trout River*

2.7.29.1. About the Trout River

- North of downtown Jacksonville
- Primary Land Use: Residential/Wetland
- Current TMDL reports: Fecal coliform with BMAP (2010) DO/Nutrients - 2203, Mercury
- Verified Impaired 2014 (draft): None
- Beneficial Use: Class III M/F (Marine 2203A, Freshwater 2203/2233)

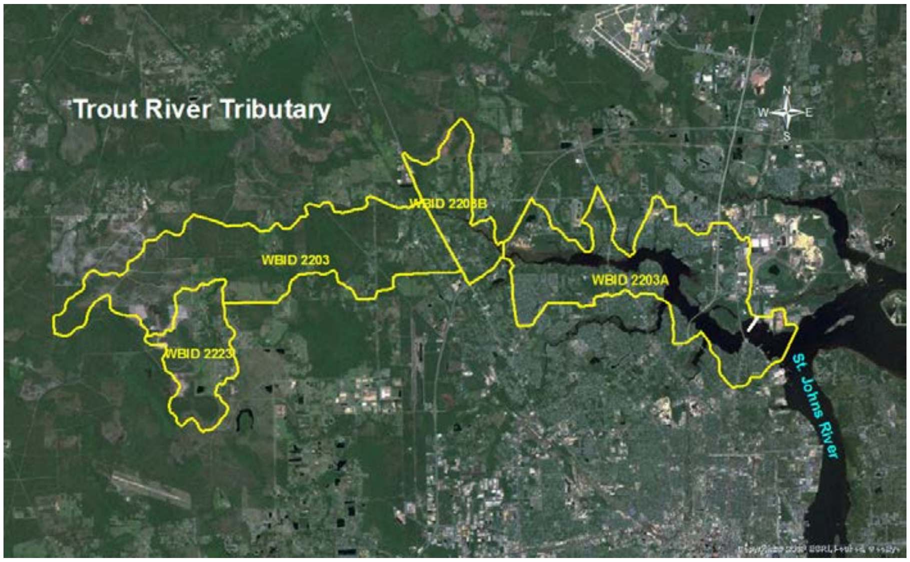


Figure 2.62 The Trout River Tributary (WBIDs 2203/2203A/2223)

2.7.29.2. Data sources

Result data were downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010c**) in the Trout River WBIDs 2203/2203A/2223 (**DEP 2014f**) shown above. The filtered dataset was used to Table 2.32.

2.7.29.3. Discussion

Water quality data for the Trout River are shown in Table 2.32. Overall (all WBIDs) average phosphorus levels were higher than the recently updated WQC (**EPA 2010a**) and average total nitrogen, dissolved oxygen and chlorophyll-a concentrations were within acceptable limits. However, nutrient levels have been found to be, on average, higher than the WQC for WBID 2203 and a TMDL report to address this issue was published in 2009 (**Magley 2009a**).

The fecal coliform level, averaged over all the stations in the Trout River (Table 2.26), is below the critical level of 2.6, which is the logarithm of the state maximum of 400 colony-forming-units (cfu) per 100 mL. However, a TMDL for fecal coliform was published in 2009 (**Wainwright and Hallas 2009c**) for WBIDs 2203 and 2203A in the Trout River. (*Note: the data analysis in the TMDL is based on different criteria than that used in this report*). Subsequently, a BMAP for the Trout River

(**DEP 2010b**) was legally adopted in August 2010. It describes sources of fecal coliform in the watershed, and completed and ongoing activities conducted by state and local agencies that are anticipated to reduce fecal coliform loading in the tributary. The BMAP describes two WBIDS: the upper Trout River (2203), and the lower Trout River (2203A). The upper Trout River watershed contains one permitted point source for industrial wastewater, and the lower Trout River contains two of those; both have numerous outfalls for stormwater discharge. The sewer system serves 100% of households in the upper Trout River watershed, and 73% in the lower Trout River watershed. Between 2001 and 2007, JEA reported 21 sanitary sewer overflows in the lower Trout River watershed, six of which potentially impacted surface waters, and none in the upper Trout River. WSEA estimates that there are 819 on-site sewage treatment and disposal systems (septic systems) in use in the upper Trout River, and 2,964 in the lower Trout River. COJ has completed two flood control projects in the lower Trout River watershed. Annual Progress Reports for this BMAP were published in 2011 (**DEP 2011c**) , 2012 (**DEP 2013i**), and 2013 (**DEP 2014g**); they lists repairs, inspections, evaluations, and other improvements conducted by JEA, the Duval County Health Department, COJ, and FDOT.

The Trout River (lower reach) was identified as being impaired for mercury, based on elevated levels of mercury in fish tissue, however this is being delisted (**DEP 2015c**) as it has been addressed by the statewide mercury TMDL (**DEP 2013a**). Iron has been added in the recent verified impaired list (**DEP 2015b**) but is potentially a natural condition in WBID 2589

Table 2.32 Water Quality Data for the Trout River

Parameter	Water Quality Criteria	Concentration			Samples	Sampling Period
		Low	Average	High		
Dissolved Oxygen (mg/L)	34% sat. FW ≥4.0 SW	0.17	5.54	14.29	487	1997 - 2014
Total Nitrogen (mg/L)	<1.54	0.32	1.24	3.35	131	1997 - 2014
Total Phosphorus (mg/L)	<0.12	0.03	0.17	0.86	146	1997 - 2014
Chlorophyll-a (µg/L)	<20 FW <11 SW	0.28	5.00	52.00	96	1997 - 2014
Arsenic (µg/L)	≤50 FW ≤50 SW	0.25	1.62	3.10	52	2006 - 2007
Cadmium (µg/L)	≤0.3 FW ≤8.8 SW	0.01	2.80	215.00	88	2000 - 2007
Copper (µg/L)	≤9.3 FW ≤3.7 SW	0.02	3.00	50.00	93	2000 - 2007
Lead (µg/L)	≤3.2 FW ≤8.5 SW	0.00	4.37	50.00	89	2000 - 2008
Nickel (µg/L)	≤52 FW ≤8.3 SW	0.00	2.53	50.00	93	2000 - 2007
Silver (µg/L)	≤0.07 FW ≤0.92 SW	0.01	0.24	5.00	56	2000 - 2007
Zinc (µg/L)	≤120 FW ≤86 SW	0.04	7.57	50.00	95	2000 - 2007
Fecal Coliform (log #/100 mL)	<2.6	-0.30	2.42	4.66	416	1999 - 2014
Turbidity (NTU)	<29	0.00	7.15	39.00	155	1997 - 2014

Note: Hardness-dependent freshwater criteria for cadmium, copper, lead, nickel, and zinc were generated based on a hardness concentration of 100 mg/L. FW=freshwater; SW=saltwater(marine).

2.7.30. Wills Branch

2.7.30.1. About the Wills Branch

- West of downtown Jacksonville Flows into the Cedar River
- Primary Land Use: Residential
- Current TMDL reports: Fecal and Total Coliform with BMAP (2010)
- Verified Impaired 2014 (draft): None
- Beneficial Use: Class III F (Recreational – Freshwater)

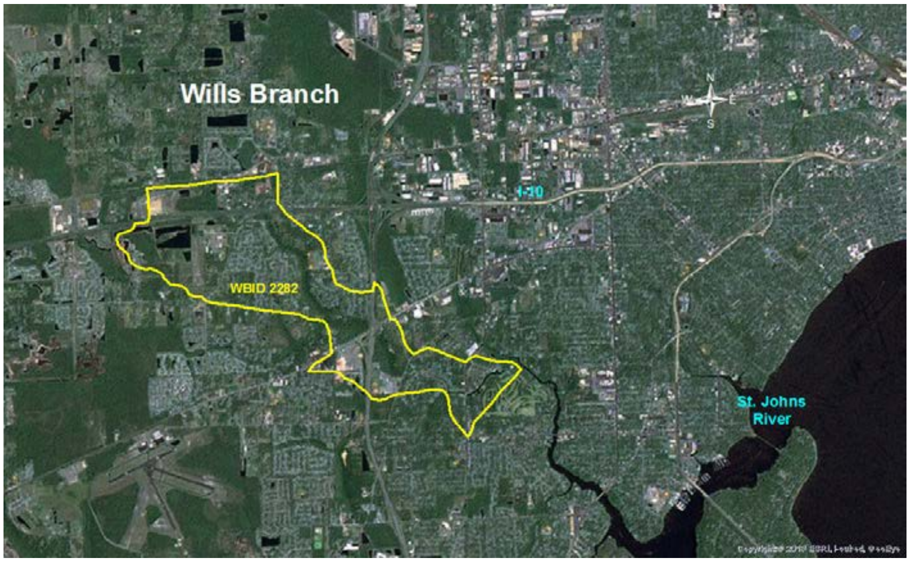


Figure 2.63 The Wills Branch Tributary (WBIDs 2282)

2.7.30.2. Data sources

Result data were downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010c**) in the Wills Branch WBID 2282 (**DEP 2014f**) shown above. The filtered dataset was used to generate Table 2.33.

2.7.30.3. Discussion

Water quality data for Wills Branch are shown in Table 2.33. Average total phosphorus, total nitrogen, dissolved oxygen and chlorophyll-a concentrations were within acceptable limits. The fecal coliform level, averaged over all the stations in Wills Branch, are above the critical level of 2.6, which is the logarithm of the state maximum of 400 colony-forming-units (cfu) per 100 mL. As a result, a TMDL for total and fecal coliform was published in 2006 (**Wainwright 2006a**) for Wills Branch. (*Note: the data analysis in the TMDL is based on different criteria than that used in this report*). Subsequently, a BMAP for Wills Branch was legally adopted in 2010 (**DEP 2010b**). Annual Progress Reports for this BMAP were published in 2011 (**DEP 2011c**), 2012 (**DEP 2013i**), and 2013 (**DEP 2013i**); they list repairs, inspections, evaluations, and other improvements conducted by JEA, the Duval County Health Department, COJ, and FDOT.

Table 2.33 Water Quality Data for Wills Branch

Parameter	Water Quality Criteria (FW)	Concentration			Samples	Sampling Period
		Low	Average	High		
Dissolved Oxygen (mg/L)	34% sat. (~3.0)	0.22	6.67	13.28	235	1999 - 2013
Total Nitrogen (mg/L)	<1.54	0.34	0.99	2.91	74	2001 - 2013
Total Phosphorus (mg/L)	<0.12	0.02	0.07	0.70	99	2002 - 2013
Chlorophyll-a (µg/L)	<20	0.10	2.80	31.00	47	2002 - 2013
Arsenic (µg/L)	≤50	0.25	0.75	2.55	30	2005 - 2008
Cadmium (µg/L)	≤0.3	0.002	1.71	90.00	64	2002 - 2008
Copper (µg/L)	≤9.3	0.02	2.52	50.00	87	2002 - 2008
Lead (µg/L)	≤3.2	0.00	5.22	50.00	79	2002 - 2008
Nickel (µg/L)	≤52	0.00	3.35	50.00	74	2002 - 2008
Silver (µg/L)	≤0.07	0.005	0.013	0.039	30	2005 - 2008
Zinc (µg/L)	≤120	0.04	6.87	50.00	80	2002 - 2008
Fecal Coliform (log #/100 mL)	<2.6	0.54	2.67	4.70	198	1999 - 2012
Turbidity (NTU)	<29	0.00	4.01	18.00	92	2001 - 2013

Note: Hardness-dependent freshwater criteria for cadmium, copper, lead, nickel, and zinc were generated based on a hardness concentration of 100 mg/L. FW=freshwater.

2.8. Salinity

Salinity is a measure of the saltiness of a mass of water. As an estuary, the lower St. Johns River experiences variable salinity with more saline waters downstream and more fresh waters upstream. Furthermore, salinity has an impact on water quality and biota in the lower St. Johns River.

The lower St. Johns River can be broken down into three ecological zones based on the salinity regimes experienced (Figure 2.64; **Hendrickson and Konwinski 1998; Malecki, et al. 2004**):

- Mesohaline

  River km 0–40 (from Mayport Inlet to Downtown Jacksonville/Fuller Warren Bridge)
  Narrower and deeper waters, well-mixed with average salinity of 14.5 parts per thousand and fast flow rate

- Oligohaline

  River km 40–75 (from Downtown Jacksonville/Fuller Warren Bridge to Doctors Lake)
  Broader and shallower waters, slow-moving and tidally active with average salinity of 2.9 parts per thousand

- Freshwater Lacustrine

  River km 75–200 (from Doctors Lake to Lake George)
  Lake-like with weaker tides and average salinity of 0.5 parts per thousand

Salinity in the lower St. Johns River is affected by tides, seasonal rainfall patterns and episodic storm and drought events. The tides are predictable by the astronomic (ocean) and estuarine (river) tide. The seasonal pattern of rainfall-derived freshwater input to the lower St. Johns River is predictable, with a majority of the rainfall occurring in the wet season from June to October (**Rao, et al. 1989**). Episodic events are less predictable and include hurricanes, tropical storms and (more frequently) nor'easters as well as droughts, like the droughts of the early 1970s, the early 1980s, 1989–1990 and 1999–2001 (**DEP 2010d**). Storm events can cause surges of coastal waters to propagate up the lower St. Johns River causing a 1–2-day spike in salinity followed by a dramatic reduction in salinity because of the lagged input of freshwater rainfall runoff from the watershed basin. Salinity increases during period of droughts because of limited freshwater rainfall-runoff input.

Storm events need not necessarily be local in order to drive storm surges and salinity spikes in the lower St. Johns River. Although non-tidal effects in river flows and salinity can be correlated with wind direction, the principal physical mechanism is not direct surface stress by winds over the river, but rather the response of ocean water level on the adjacent shelf that then forces the flow and salinity in the river. In short, the lower St. Johns River is primarily affected by remote winds and is secondarily affected by local winds (**Bacopoulos, et al. 2009**). Low frequency, synoptic-scale ocean water level variability is at least as important a factor as storm events in causing distinct pulses of salinity in the river. Synoptic-scale events have 3 to 12 day time scales and are much more frequent than hurricanes and tropical storms.

This section of the report covers three sub-topics of salinity in the lower St. Johns River:

- Salinity Models: Models currently being used on the lower St. Johns River and the differences between the models and how they are being used
- Longitudinal Salinity Variation: Longitudinal salinity variations using time-series data including episodic storm events
- Biological Impacts: The biological impacts of salinity

2.8.1. Salinity Models

This sub-section covers models currently being used on the lower St. Johns River and the differences between the models and how they are being used.

As a preface, models are used in science to mimic and study physical processes. For example, Newton's law governs gravitationally forced motion, like an apple falling from a tree, which can be modeled on a computer to provide simulations for various physical scenarios, like if the object were more or less massive, if the object were dropped from more or less height, etc. The models presented in this sub-section are used to mimic the physical processes of hydrodynamics and salinity. Models are developed, then applied for a specific case (this is called 'calibration') and applied again for a different case (this is called 'validation'). The performance of the model to simulate the physical process(es) is measured in the calibration and validation procedures. There is no binary (yes or no) outcome from the calibration and validation procedures; rather, quantitative measures of performance are used to support the extent that a model has been successfully calibrated and validated. The model cases presented below are from two models that are widely accepted within the coastal and river modeling community and that have undergone extensive development, calibration and validation.

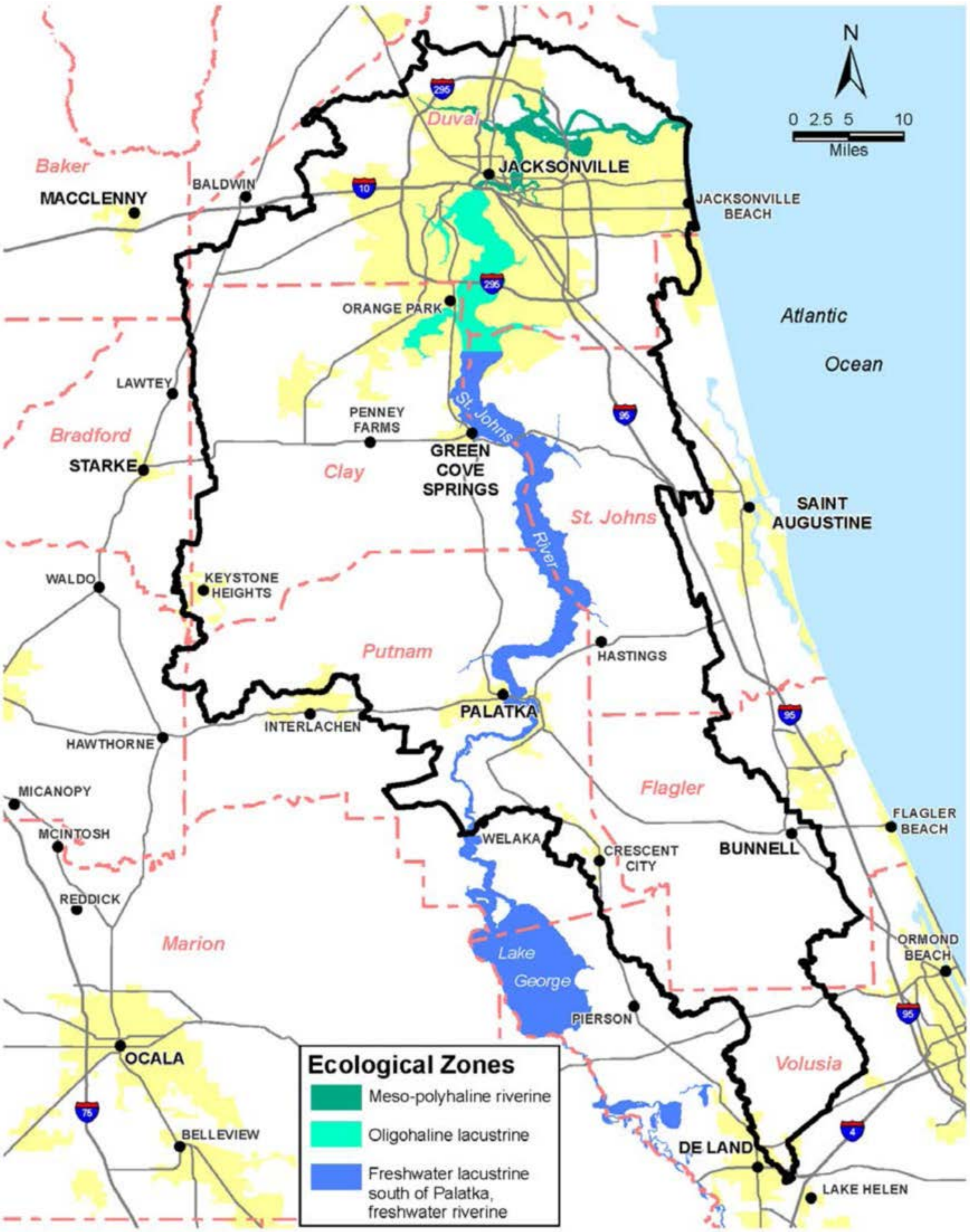


Figure 2.64 Map of the Ecological (Salinity) Zones of the Lower St. Johns River

There are two models covered in this sub-section:

- EFDC—Environmental Fluid Dynamics Code

  Used by the United States Army Corps of Engineers
  Used by the St. Johns River Water Management District
  Used in private industry—examples cited are from Taylor Engineering, Inc.

- ADCIRC—ADvanced CIRCulation

  Used in the academic arena—examples cited are from the University of North Florida and the University of Central Florida

2.8.1.1. EFDC—Environmental Fluid Dynamics Code

The Environmental Fluid Dynamics Code (EFDC) (**Hamrick 1992**) is a three-dimensional hydrodynamic model capable of simulating changes in water level, velocity, discharge, salinity and water age (a measure of flushing rate) due to changes in inflows from multiple sources and locations. Some of the model features that make EFDC attractive for salinity modeling in the lower St. Johns River include:

- Advection-Diffusion

  Allows for simulation of salinity and water age

- Surface Wind Stress

  Allows for wind forcing to be applied in the model

- Two-Dimensional Flows

  Allows for simulation of horizontal flows and circulation in lakes

- Three-Dimensional Flows

  Allows for simulation of return flows generated by wind setup in lakes

- Dynamic Coupling of Salinity and Density

  Allows for simulation of density stratification and the subsequent baroclinic, estuarine circulation

Further reference information on EFDC can be found online (**EPA 2014**).

EFDC is used by the United States Army Corps of Engineers (**Liu, et al. 2013**), the St. Johns River Water Management District (**SJRWMD 2012b; Sucsy and Morris IV 2001**) and in private industry, e.g. Taylor Engineering, Inc. (**Liu, et al. 2013**).

The St. Johns River Water Management District continues to employ EFDC, for example, for total maximum daily loadings (**Sucsy and Morris IV 2001**) and water supply impact study (**SJRWMD 2012b**) (Figure 2.65). The EFDC hydrodynamic model grid for the lower St. Johns River includes Lake George and Crescent Lake, the main river stem and a portion of the offshore domain. The salt marshes north and south of the lower St. Johns River near the inlet are included in the model grid as water storage areas.

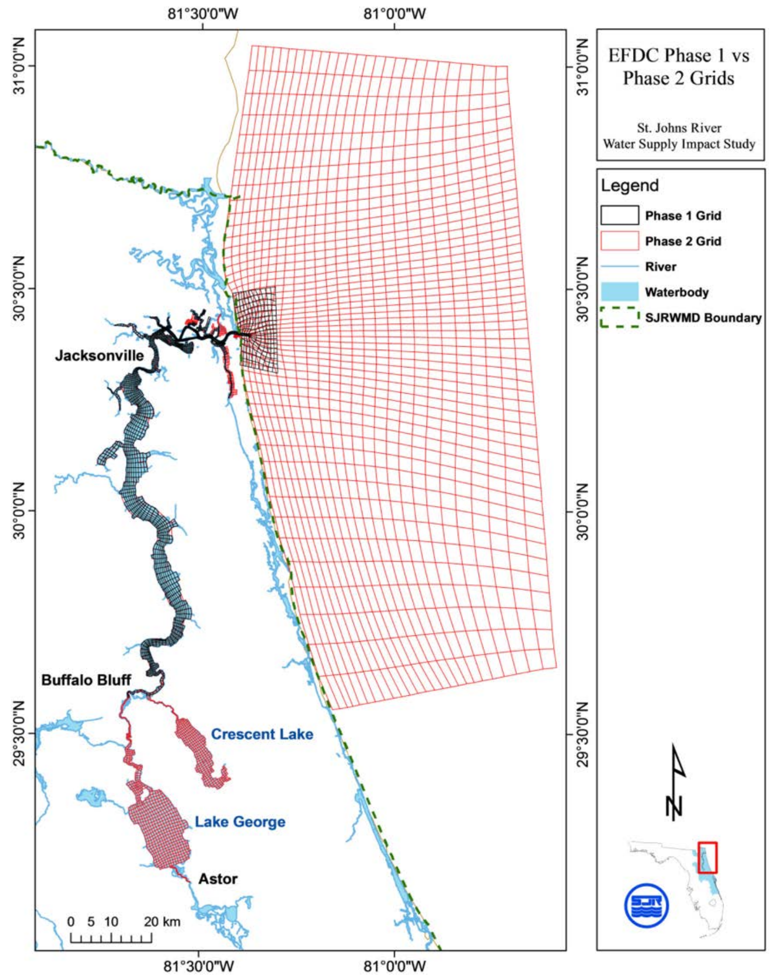


*Figure 2.65 EFDC Hydrodynamic Model Grid (**SJRWMD 2012a**)*

Resolution of the grid cells is generally 0.5–1 km with finer resolution going down to 50–100 m to define the finer features of the lower St. Johns River, like the model grid spanning four grid cells across the narrow river channel through Downtown Jacksonville (Figure 2.66).

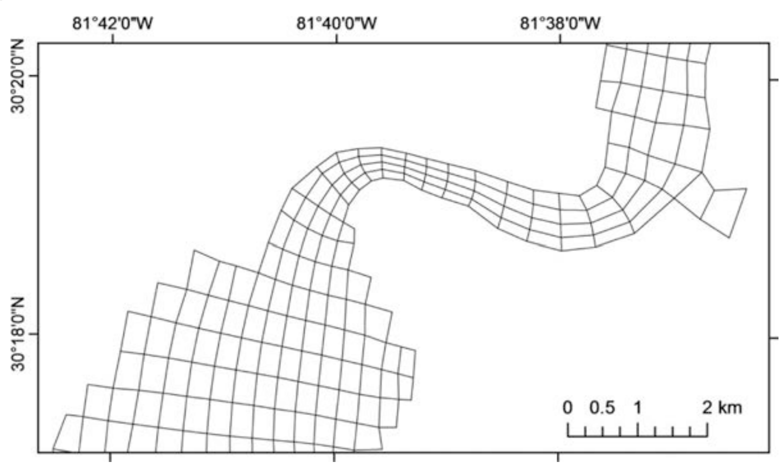


*Figure 2.66 EFDC Hydrodynamic Model Grid—Zoom of Downtown Jacksonville (**SJRWMD 2012a**)*

Calibration of EFDC for the lower St. Johns River included specifying or adjusting the following data and input parameters (**Sucsy and Morris IV 2001**):

- Bottom Bathymetry
- Bottom Roughness
- Tidal Water Level at the Open-Ocean Boundary
- Salinity at the Open-Ocean Boundary
- Number of Vertical Layers in the Model
- Non-Reflective Upstream Open Boundary

The main calibration parameter for EFDC was bottom roughness, which is the usual case for hydrodynamic and salinity modeling. EFDC calibration was performed for 1997–1999 and EFDC validation was performed for 1996–2005. Model performance measures were computed for water levels, discharges and salinity simulated by EFDC. Water levels were simulated by EFDC to within on-average 95% (r^2) of observed data and discharges and salinity were simulated by EFDC to within on-average 85% (r^2) of observed data. The EFDC model validation proved capable of simulating salinity variations from Mayport Inlet (river km 0) to the entrance of Lake George (river km 190) (Figure 2.67).

One conclusion from the salinity sub-study in the water supply impact study of the lower St. Johns River (**SJRWMD 2012b**) was stated as (page 5-308) "although the model shows a realistic response to observed salinity at widely spaced locations, there is a paucity of data for confirming the model's dynamic simulation of salinity at tidal scales," which becomes further apparent in the later sub-section(s) of this section.

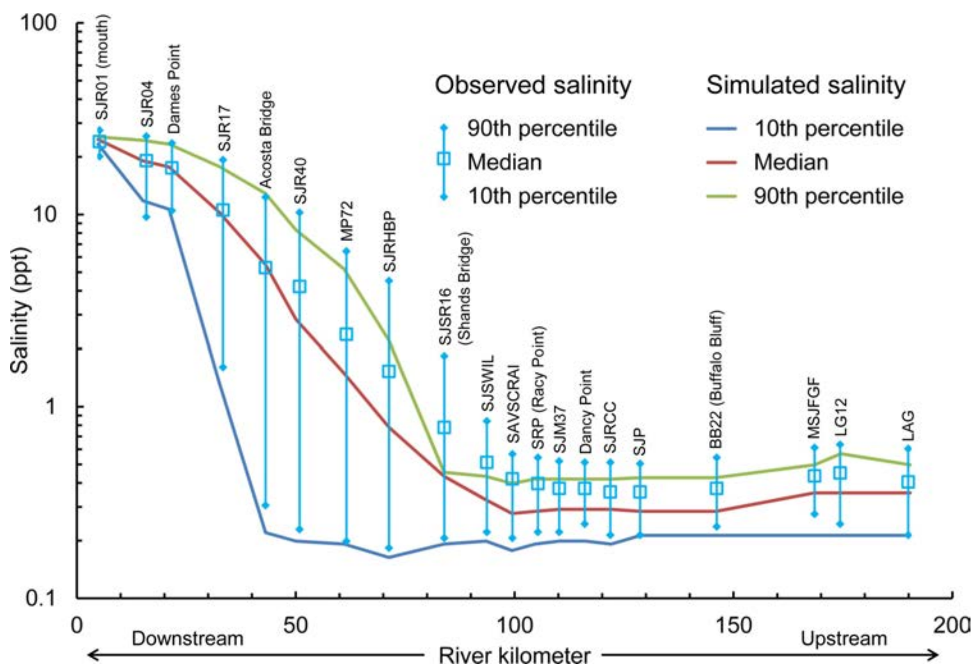


*Figure 2.67 Salinity Variations Simulated by EFDC Compared to Observed Data for the Lower 190 km of the St. Johns River (**SJRWMD 2012b**)*

2.8.1.2. <u>ADCIRC—ADvanced CIRCulation</u>

The ADvanced CIRCulation (ADCIRC) code (**Luettich, et al. 1992**) is a two-dimensional hydrodynamic model capable of simulating water levels and depth-integrated velocities for tide, wind and freshwater river-influx forcing scenarios. Recent developments of ADCIRC (**Kubatko, et al. 2006**) have given the model the capability to simulate salinity. Some of the model features that make ADCIRC attractive for salinity modeling in the lower St. Johns River include:

- Advection-Diffusion

  Allows for simulation of salinity

- Surface Wind Stress

  Allows for wind forcing to be applied in the model

- Unstructured Triangulation

  Allows for flexible model-domain definition

- Two-Dimensional Flows

  Allows for simulation of depth-integrated velocities and flows

Further reference information on ADCIRC can be found online (**UNC 2014**).

ADCIRC is used in the academic area, like at the University of North Florida and the University of Central Florida.

An ADCIRC model has been developed, calibrated and validated for the lower St. Johns River (**Bacopoulos, et al. 2012**). The ADCIRC model mesh includes a telescopic view into the lower St. Johns River from the large-scale western North Atlantic Ocean, Caribbean Sea and Gulf of Mexico (**Hagen, et al. 2006**) (Figure 2.68 The ADCIRC model mesh represents the lower St. Johns River up to and including Lake George, the salt marshes north and south of the lower St. Johns River near the inlet and a localized offshore zone outside of the inlet (Figure 2.69). Resolution of the mesh elements ranges from hundreds of meters for the main river stem, or even greater in element size for the offshore zone, to tens of meters for tidal creeks, narrow channels and other fine features of the lower St. Johns River.

Figure 2.68 ADCIRC Model Mesh Telescoping from the Western North Atlantic Ocean, Caribbean Sea and Gulf of Mexico into the Lower St. Johns River (Hagen, et al. 2006)

ADCIRC calibration was performed for 1995–1997, with bottom roughness as the main calibration parameter used (**Bacopoulos, et al. 2012**), and ADCIRC validation was performed for May, June and July 2009. Model performance measures were computed for water levels, discharges and daily discharges simulated by ADCIRC. Discharges were simulated by ADCIRC to within on-average 20% error (RMS) relative to observed data, water levels were simulated by ADCIRC to within on-average 15% error (RMS) relative to observed and daily discharges were simulated by ADCIRC to within on-average 30% error (RMS). These errors may seem large upon initial review; however, consider that these errors are with regards to the model's ability to simulate to complete hydrodynamic signal, including tide-, runoff-, wind- and remote-driven processes, as measured against comparable observations that include the full hydrodynamic signal.

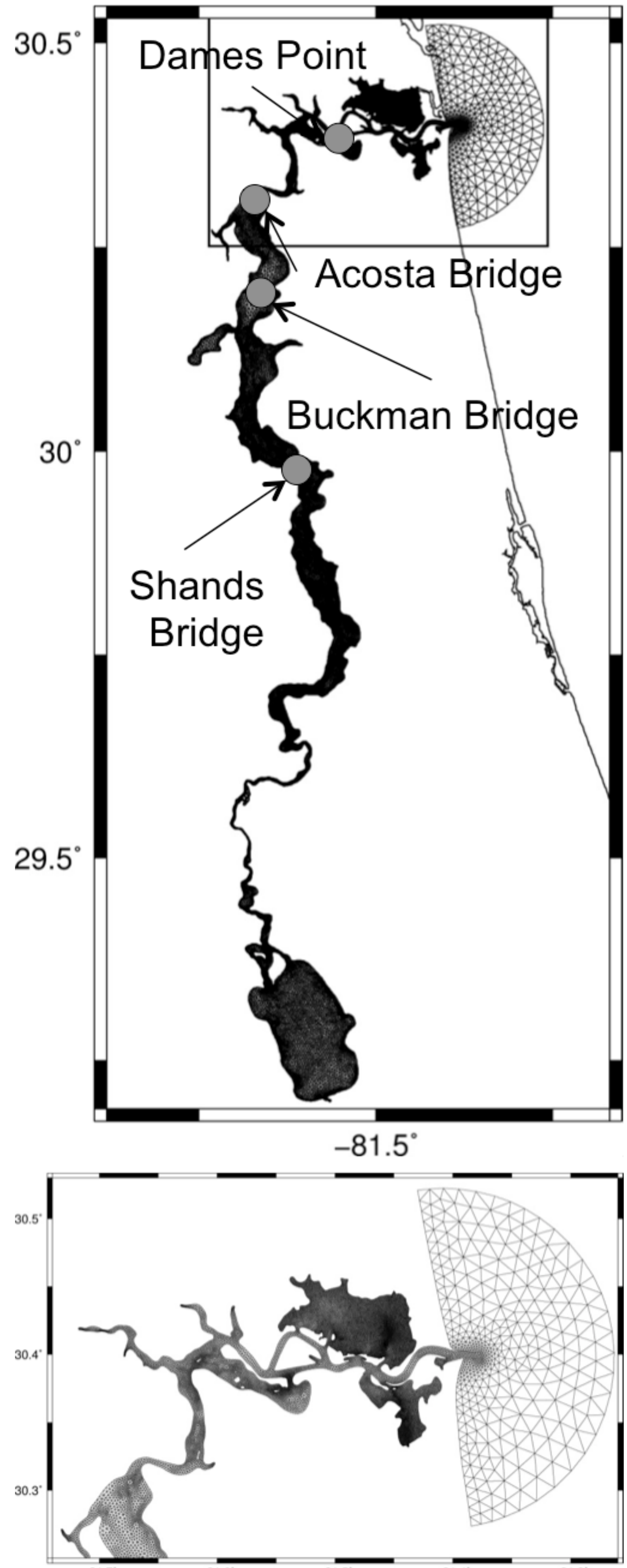


*Figure 2.69 ADCIRC Model Mesh Localized for the Lower St. Johns River (**Bacopoulos, et al. 2012**) with Four Salinity Monitoring Stations*

Additional simulations were performed for the lower St. Johns River for three one-month periods:

- June 13–July 13, 1999

  Referred to as 'High Extreme' because the salinity regime in the river was relatively saline for the 30-day period

- September 21–October 21, 1999

  Referred to as 'Most Variable' because the salinity regime in the river was longitudinally varied for the 30-day period

- October 30–November 29, 1999

  Referred to as 'Low Extreme' because the salinity regime in the river was relatively fresh for the 30-day period

The simulations for the three one-month periods in 1999 proved the ADCIRC model's capability to simulate salinity variations at Dames Point (river km 20) (Figure 2.70). This level of performance demonstrates the ADCIRC model's ability to recreate short-term events, like the reduction in salinity during June 20–July 4, 1999, the rise and spike in salinity during October 12–19, 1999 and the fluctuations in salinity during November 13–20, 1999. The model results shown clarify how the ADCIRC model incorporates tide, wind and freshwater river influx as driving forces for the simulation of salinity response in the lower St. Johns River.

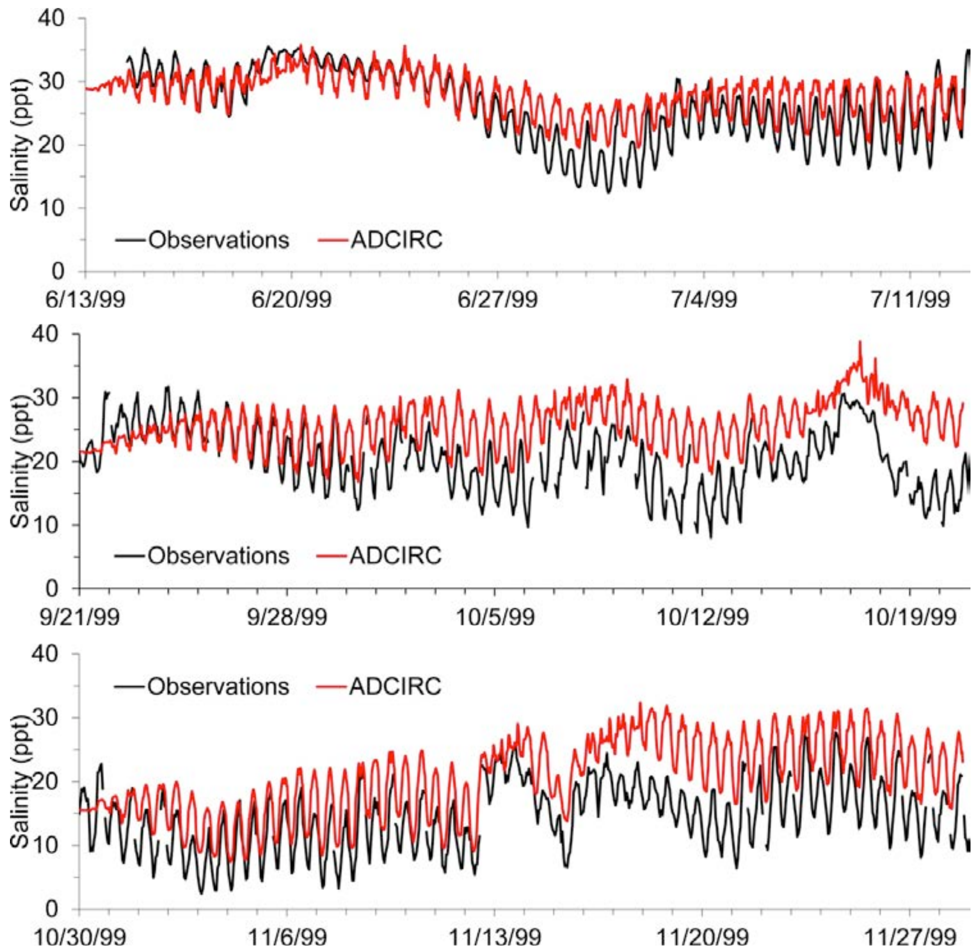


Figure 2.70 ADCIRC-Modeled Salinity Versus Observations at Dames Point for Three One-Month Periods in 1999

As a disclaimer, the ADCIRC model simulations for the three one-month periods in 1999 are, as of the writing of this report, fresh and brand new. There are model developments, calibration and validation still to be done on the ADCIRC simulations for modeling salinity in the lower St. Johns River; however, even as hot-of-the-press, these ADCIRC model results nonetheless capture the tidal and episodic non-tidal variations in salinity for the lower St. Johns River, as subjected to driving forces of tides, winds and freshwater river influxes.

In conclusion, the Environmental Fluid Dynamics Code (EFDC) and the ADvanced CIRCulation (ADCIRC) code were summarized in this sub-section on salinity models. Salinity fluctuations were shown to be captured by the EFDC model, namely concerning the variability of salinity fluctuations along the 190-km stretch of the lower St. Johns River (Figure 2.4). Salinity fluctuations were shown to be captured by the ADCIRC model, namely concerning the tidal and short-term (i.e., episodic) salinity fluctuations (Figure 2.7).

It might be useful to clarify which model (EFDC vs. ADCIRC) works better for the different salinity zones of the lower St. Johns River. This effort will require care, and it will be carried out and shown in next year's report.

2.8.2. Depth Variation of Salinity

This sub-section covers depth variation of salinity by analysis of depth-dependent time-series data including episodic storm events. Continuous salinity data at 1-hour interval are available for six locations in the lower St. Johns River from early 1995, collected as a joint effort between the United States Geological Survey and the St. Johns River Water Management District for the study of total maximum daily loadings (**Sucsy and Morris IV 2001**). The four most downstream stations are focused in this sub-section on longitudinal salinity variations (Figure 2.6):

- Dames Point

  River km 20

- Acosta Bridge

  River km 40

- Buckman Bridge

  River km 60

- Shands Bridge

  River km 80

Salinity data were collected at three different depths within the local water column: top level; mid-level; and lower level. Figure 2.71 shows time-series data of salinity at the three different depths, over the four salinity monitoring stations (Figure 2.69) for the 'Most Variable' period (September 21 – October 21, 1999). The plots show little to no depth variation of salinity at the three upstream stations (Acosta Bridge, Buckman Bridge and Shands Bridge) and show some depth variation of salinity at the downstream station (Dames Point), which is corroborated by the calculated differences of top salinity minus bottom salinity. At Acosta Bridge, Buckman Bridge and Shands Bridge, top-bottom salinity differences generally are negligible, while sometimes the salinity difference can be measureable (e.g., reaching as low as –5 ppt and as high as 2 ppt). At Dames Point, top-bottom salinity differences generally range from –5 to 5 ppt, while sometimes the salinity difference can be more (e.g., reaching as low as –9 ppt and as high as 13 ppt). Considering time averages, top-bottom salinity differences are 1.5, –0.1, –0.3 and –0.1 ppt at Dames Point, Acosta Bridge, Buckman Bridge and Shands Bridge, respectively.

Figure 2.72 shows the bathymetric depth, the three depth-levels where salinity data were collected and the corresponding top-, mid- and bottom-level salinity data (displayed as average plus/minus standard deviation: AVE ± STD) for the four salinity-monitoring stations. At Dames Point, there is some depth variation of salinity such that the top-level AVE ± STD salinity is 21.4 ± 4.4 ppt, the mid-level AVE ± STD salinity is 21.6 ± 4.8 ppt and the bottom-level AVE ± STD salinity is 20.1 ± 5.1 ppt. At Acosta Bridge, Buckman Bridge and Shands Bridge, there is essentially no depth variation of salinity.

The data analysis suggests that salinity in the lower St. Johns River is vertically well-mixed, especially upstream of Acosta Bridge, located at river km 40; though, the vertical salinity structure can become partially stratified near the river mouth (i.e., downstream of Dames Point, located at river km 20). It is strange that, at Dames Point, the top measurement of salinity would be greater than the bottom measurement of salinity, which is subject for further investigation. At the least, there appears to be some kind of sub-tidal frequency with the top-to-bottom salinity difference. There is question as to the measurement device used, namely with regards to measuring relatively high salinity at Shands Bridge (approximately 3 ppt), which usually has salinity near zero and at most 0.5 ppt (**Hackney 2015b**). Also, there is the question of the amount of salinity in the lower St. Johns River that is ocean-derived versus spring-fed.

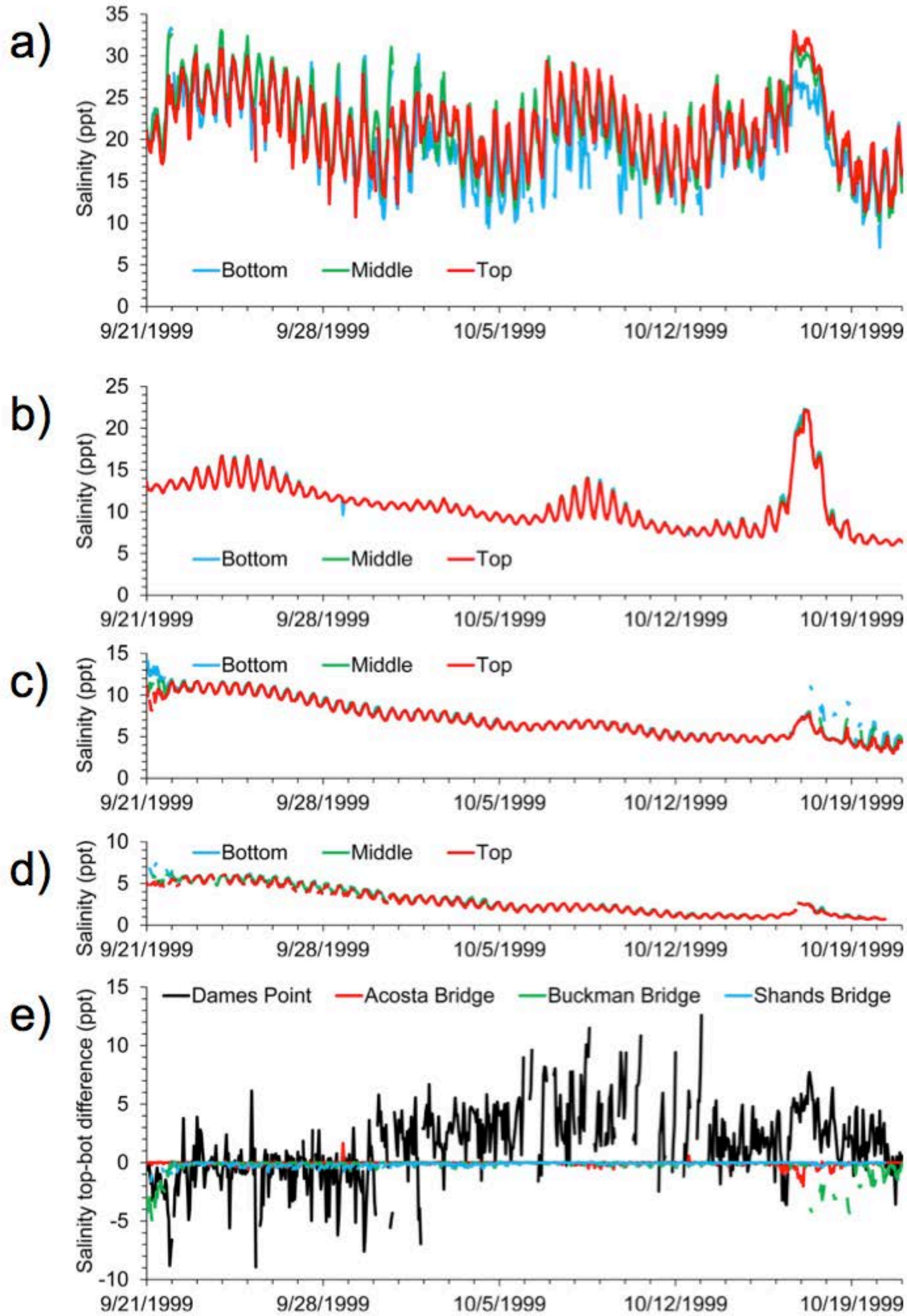


Figure 2.71 Depth-Dependent Salinity at the Four Salinity Monitoring Stations for the 'Most Variable' Period (September 21–October 21, 1999): a) Dames Point; b) Acosta Bridge; c) Buckman Bridge; d) Shands Bridge; and e) Salinity Differences, as Computed by Top Salinity Minus Bottom Salinity, for the Four Stations

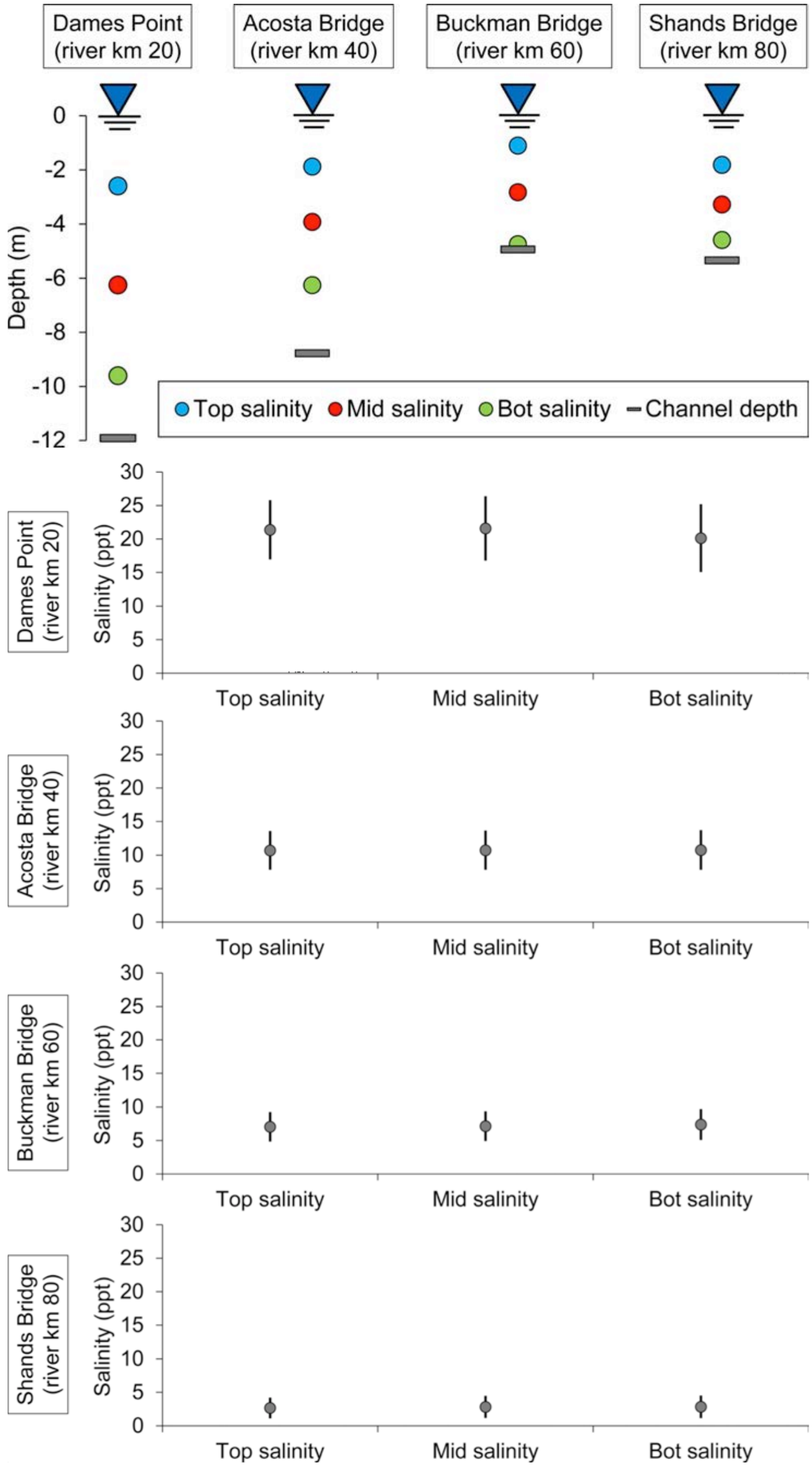


Figure 2.72 (Top Panel) Depths of Salinity Measurement Device within Vertical Water Column at Four Gaging Stations, along with Depth of Local Channel Bottom; and (Bottom Panel) Salinity Data as Average Plus and Minus One Standard Deviation for Top, Middle and Bottom Measurement Levels, for Four Gaging Stations

2.8.3. Longitudinal Salinity Variations

This sub-section covers longitudinal salinity variations using time-series data including episodic storm events. The data are available for the four salinity-monitoring stations (Dames Point—river km 20; Acosta Bridge—river km 40; Buckman Bridge—river km 60; and Shands Bridge—river km 80). This sub-section focuses on the depth average (it was cited earlier in the text as 'depth-integrated,' which is referring to the same concept) of the salinity data and how salinity varies over the four locations in the lower St. Johns River (from river km 20 to river km 80). The salinity data were depth-averaged for the three levels (high, middle and low), over the four salinity-monitoring stations (Figure 2.6) for the aforementioned three one-month periods in 1999 (Figure 2.73).

Salinity in the lower St. Johns River fluctuates semi-diurnally (approximately every 12 hours and 25 minutes) which is dictated by the astronomic (ocean) and estuarine (river) tide. The tidally driven salinity fluctuations are greatest (approximately 10 ppt in range at Dames Point) when salinity is generally low, like in the case of the 'Low Extreme' period (October 30–November 29, 1999), and least (approximately 6 ppt in range at Dames Point) when salinity is generally high, like in the case of the 'High Extreme' period (June 13–July 13, 1999). The signal ('signal' just being a compact word to represent the tidally driven salinity fluctuation) becomes progressively weaker with greater distance upstream, which corresponds with the diminishing tidal hydrodynamics with greater distance up the lower St. Johns River (**Bacopoulos, et al. 2012**). Salinity at Shands Bridge varies minimally with only 2–3 ppt of range.

Salinity is generally high for the 'High Extreme' period (June 13–July 13, 1999) with near complete seawater (35 ppt) experienced at Dames Point and salinity reaching near 20, 12 and 5 ppt for Acosta Bridge, Buckman Bridge and Shands Bridge, respectively, for the first two weeks of the record. On the other hand, consider the generally low salinity for the 'Low Extreme' period (October 30–November 29, 1999), when the lower St. Johns River became nearly entirely fresh (0 ppt).

Salinity spikes on October 15–19, 1999, which is due to Hurricane Irene (**Avila 1999**), and is especially noticeable at Dames Point and Acosta Bridge while lesser noticeable at Buckman Bridge and Shands Bridge. As a representative episodic storm event, Hurricane Irene caused salinity levels in the lower St. Johns River to fluctuate by over 10 ppt in just a matter of days.

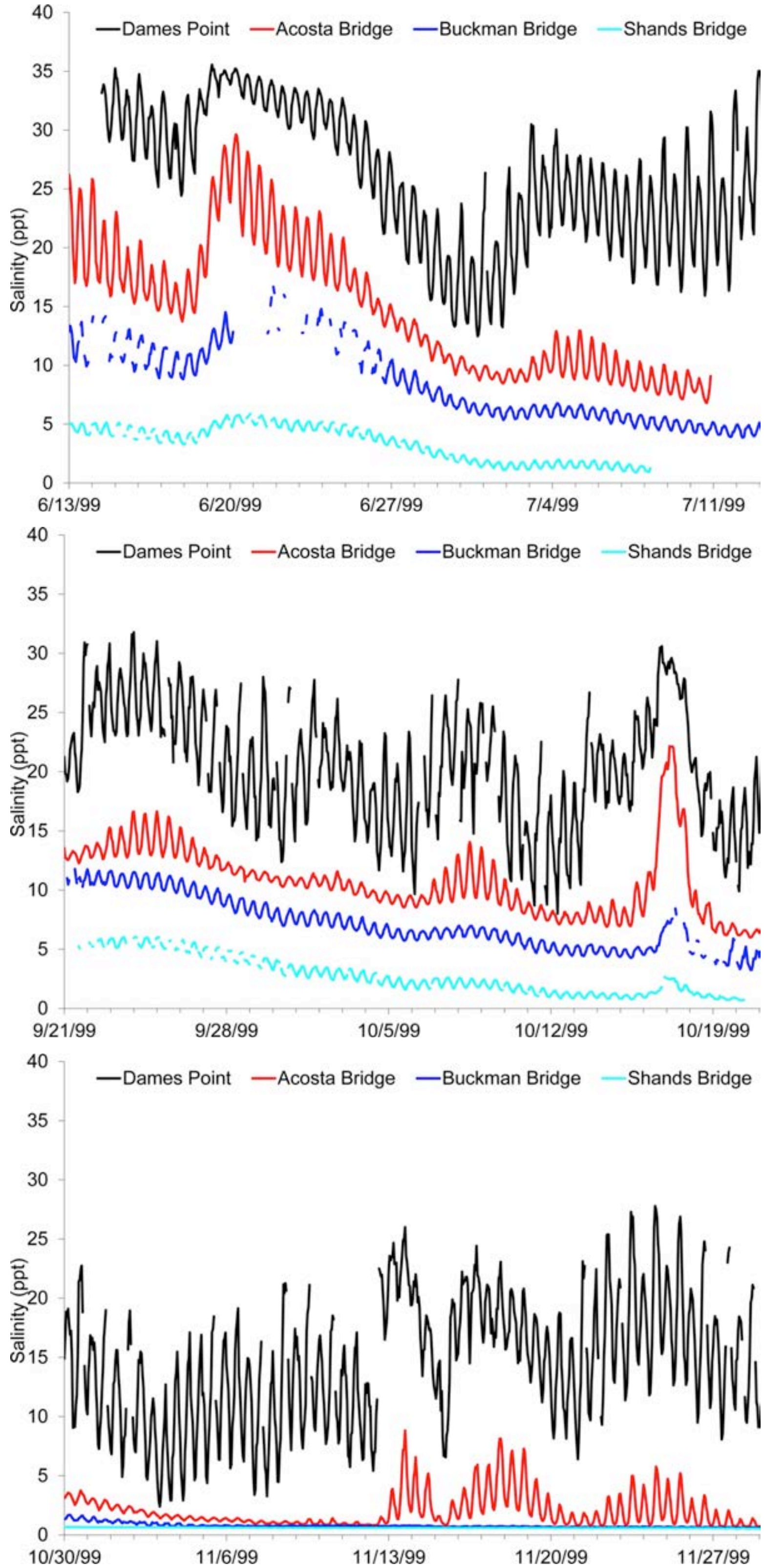


Figure 2.73 Depth-Averaged Salinity at the Four Salinity Monitoring Stations for the Three One-Month Periods in 1999

In closing, the longitudinal variation of salinity in the lower St. Johns River covers the full range of salinity (0–35 ppt), as was evidenced in the salinity data available from the four salinity monitoring stations, which span river km 20–80. In addition to the longitudinal variation of salinity in the lower St. Johns River, short-term events, like Hurricane Irene that was observed in the salinity data, are able to cause salinity spikes and jumps in salinity by over 10 ppt for two to three days.

2.8.4. Biological Impacts

This sub-section covers potential biological impacts of salinity on the flora and fauna of LSJRB. Salinity increases as a result of the environment can be looked at in terms of 1) periodic short term events like storms that result in abrupt salinity spikes for less than 14 days. 2) Intermediate term events like droughts that result in elevated salinity for some weeks. 3) Long term changes as a result of sea levels rising over many years. 4) Salinity can also be altered due to human activities in the basin such as reduced freshwater inflows to the river caused by dams, surface water withdrawals, or significant pumping of ground water. In addition, activities such as harbor deepening tend to increase salt water entering an estuary thus driving up the salinity (**Sucsy 2008**).

The LSJRB supports a diverse community of living organisms that are important to the ecosystem, are affected by salinity, and have significant recreational and commercial economic value. Submerged aquatic vegetation and invertebrate bottom dwelling organisms play an important role in shaping habitat so that it is able to support fish and other wildlife. Examples of commercially valuable organisms include blue crabs, bait shrimp, and stone crabs. In 2013, Clay, Duval, Flagler, Putnam and St. Johns Counties reported a total commercial crab harvest of 1,615,232 lbs. (73%); and a fish harvest of some 570,509 lbs. (**FWRI 2015b**). In general, stripped mullet, whiting and flounder have been the most caught species, but recreationally, red drum, spotted sea trout, croaker, sheepshead, flounder, largemouth bass, and blue gill are most important to anglers.

For all the species of fish and invertebrates mentioned in this report there are a few themes of importance:

- Each species plays an essential role in the ecosystem, with many interdependencies (predator, prey relationships).
- Each species requires essential habitats for an important life stage (coastal and in the river).
- Each species is of commercial and recreational value that is supported by the rest of the ecosystem which also has value.

2.8.4.1. Macroinvertebrates

These are animals without a backbone that live in or on river bottom sediments including small crabs, snails, shrimp, clams, insects, worms, and barnacles among others species (see section 4.3). These organisms affect oxygen levels in the sediment, as well as sediment size, which in turn affect what is able to live and grow in proximity to them. Macroinvertebrates are useful indicators of environmental stress and species change as one transitions from higher to low salinity. FDEP data from 1974-1999 indicated that the northern river section was dominated by barnacles, polychaetes, and amphipods, and the southern river area was dominated by molluscs, amphipods, polychaetes, oligochaetes, and fly larvae. During the 1980s, the north section was dominated by polychaetes and barnacles, while the southern portion was mostly oligochaetes and fly larvae. In the 1990's another shift occurred due to salinity where the northern stations were dominated by amphipods, molluscs, polychaetes, and barnacles and the southern areas by bivalves and snails (**Evans, et al. 2004; Montagna, et al. 2011**).

Evans, et al. 2004 states that freshwater areas of the river are affected by increasing salinity and that the concern is this will likely change the invertebrate community, the result could be significant negative impacts on the quality and quantity of freshwater fish species harvested from LSJRB. At this time there is a lack of recent data on macroinvertebrates and how parameters such as low dissolved oxygen, sediment quality, and toxic substances in the environment may interact with changes in salinity levels.

2.8.4.2. Blue Crabs

The blue crab is a common benthic predator that represents the largest commercial fishery in LSJRB. Successful crab reproduction relies on a particular set of salinity conditions at specific times in the life cycle. Females carry fertilized eggs and migrate towards the more marine waters near the mouth of the river where they will release their eggs into the water (see section 3.3.2 Fisheries). After some time adrift, wind and currents transport the megalops larvae back to the estuarine parts of the river where they settle in submerged aquatic vegetation (SAV) that serves as a nursery.

One concern that may negatively affect the recruitment of new crabs into the population is that with increasing salinity levels, the salinity transition zone will shift further south increasing the distance that female crabs with eggs will need to travel in order to reach the river mouth. This could ultimately affect recruitment.

Another concern is associated with nursery habitat. Increasing salinity further south in the river will negatively impact submerged aquatic vegetation that is required for young crabs.

Also, since the price of crustaceans in general is dependent on size, yet another concern may be diminishing size of adult crabs. There are several studies mentioned in **Tagatz 1968b** that report an inverse relationship between salinity and size. The higher the salinity of water in which growth occurs the smaller the adult sizes. This may be due to the crabs absorbing more water in lower salinity conditions when they molt (bigger crab) as opposed to them absorbing less water under higher salinity conditions (smaller crab). As a result, this could translate into lower income per pound for commercial harvesters for a particular level of fishing effort.

Ecologically speaking, blue crabs are very important in both the benthic and planktonic food webs in the St. Johns River. They are important predators that can affect the abundance of many macroinvertebrates such as bivalves, smaller crabs, and worms. They are also important prey for many species. Smaller crabs provide food for drum, spot, croaker, seatrout and catfish, while sharks and rays eat larger individuals (**White, et al. 2009**).

2.8.4.3. Shrimp

Three principle shrimp species found in the area include most commonly White Shrimp (*Litopenaeus setiferus),* Brown Shrimp (*Farfantepenaeus aztecus),* and Pink Shrimp *(Farfantepenaeus duorarum)*. All are omnivores feeding on worms, amphipods, mollusks, copepods, isopods and organic detritus. White shrimp spawn from April to October; pink shrimp (February to March) and brown shrimp (March to September) (**FWRI 2008a**). All species spawn offshore in deeper waters with larvae developing in the plankton and eventually settling in salt marsh tidal creeks with appropriate salinities within the estuaries. Changes in salinity will cause a change in the distribution of these early life stages that could potentially affect the number of adults returning offshore. Shrimp are important in both benthic and planktonic food webs in SJR. They affect the abundance of many small macroinvertebrates. They are also important prey for many other species. As small planktonic individuals, the shrimp post-larvae and juveniles forms provide food for other estuarine species like sheepshead minnows, insect larvae, killifish and blue crabs. As adult shrimp, they are preyed on by finfish found within the river. The commercial shrimp fishery is one of the largest fisheries in the region, but most shrimp for human consumption are caught offshore.

2.8.4.4. Fish

The SJRWMD (**McCloud 2010**) compared current FWRI fish data with those collected by Tagatz in 1968 (**Tagatz 1968c**). The data suggested that at some areas of the river, fish communities were 50% different between 1968 and the 2001-2006 time periods. The differences in fish communities in these areas may have been the result of a transition zone between marine and freshwater moving further upstream (Figures 2.74 thru 2.76). It is important to note that most fish are able to move from an area in response to changes in environmental factors such as salinity, dissolved oxygen, and temperature. However, sessile species of plants and animals that are closely associated with the bottom substrate cannot move and can be impacted by such variations depending on the frequency and duration of events. Moreover, for the species that can move, there may be important life stages for these that dependent on water quality parameters being relatively stable at essential habitat areas like nursery and spawning grounds. So although fish can move, they may not be able to reproduce effectively because essential habitat has been disrupted that affects a particular life stage.

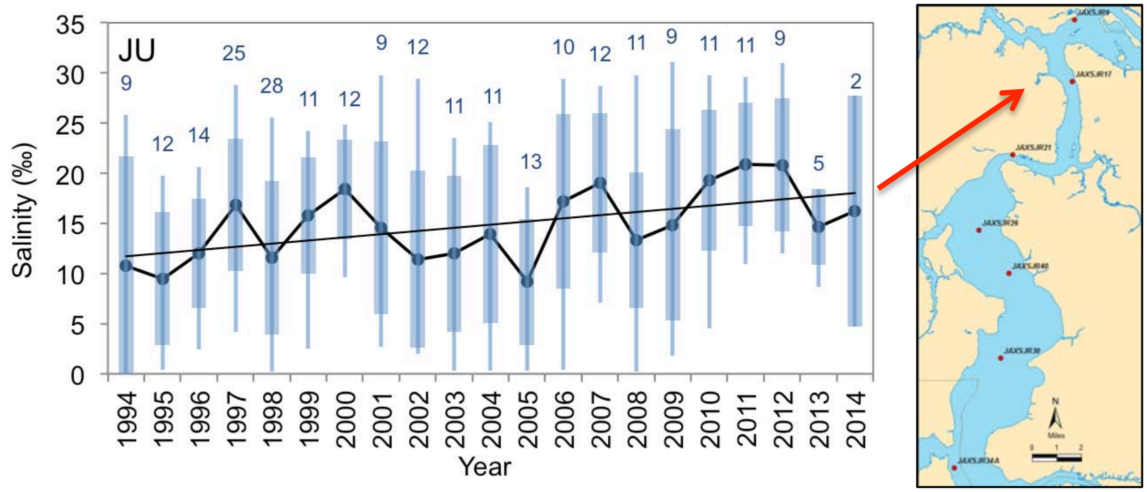


Figure 2.74 Salinity on the bottom of SJR (Station SJR17 near JU) values above the bars indicate the numbers of observations. Solid line (mean), vertical lines (maximum and minimum), and bars (Standard Deviation of the mean). Data source: ***Deuerling 2015****. SJR17 mean 26.06 ppt (S.D.±4.18 for the maxima). Note that only two observations were made in 2014.*

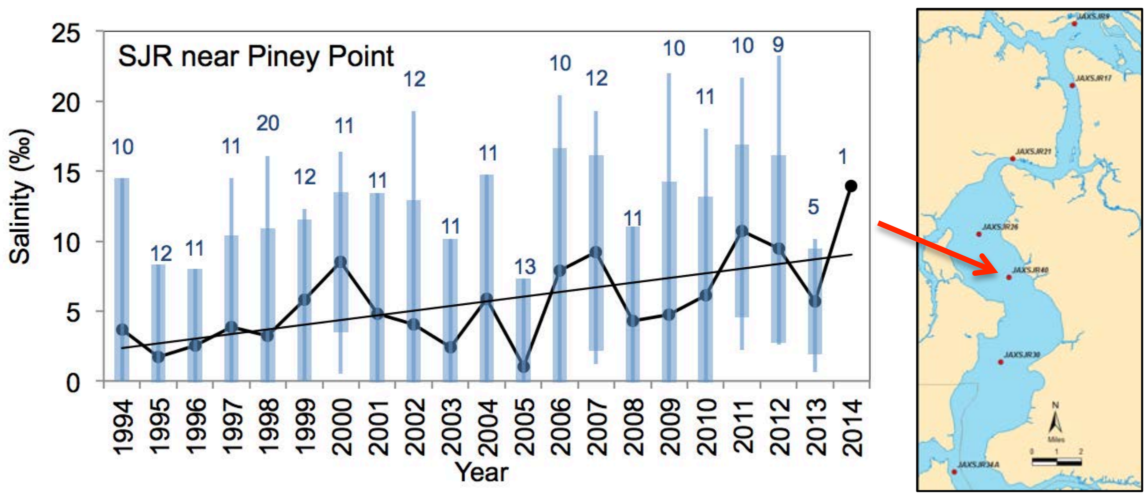


Figure 2.75 Salinity on the bottom of SJR (Main stem Station SJR40 located mid-channel N. of Piney Pt. 100 m west of green marker 5) values above the bars indicate the numbers of observations. Solid line (mean), vertical lines (maximum and minimum), and bars (Standard Deviation of the mean). Data source: ***Deuerling 2015****. SJR40 mean 14.53 ppt (S.D.±5.39 for the maxima). Note that only one observation was made in 2014.*

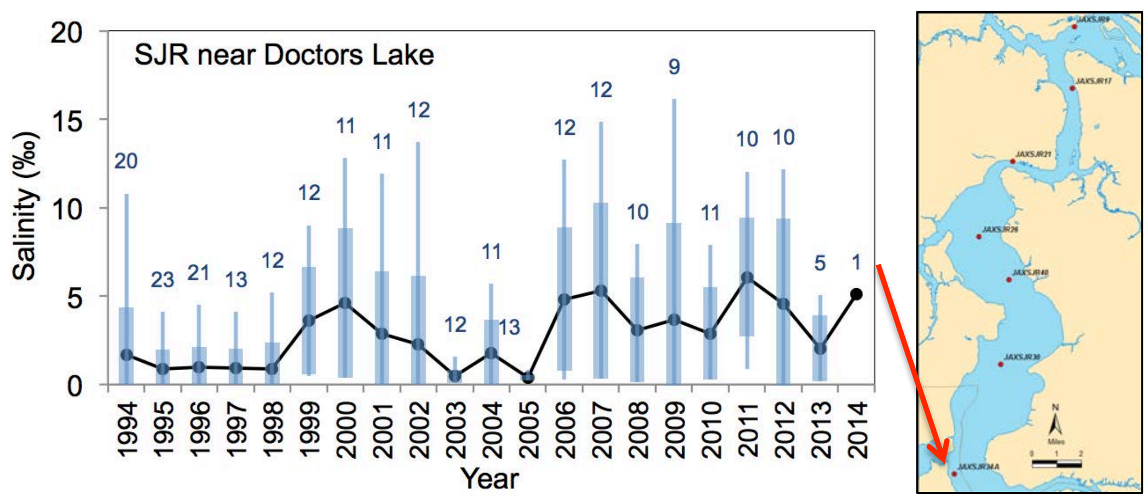


Figure 2.76 Salinity on the bottom of SJR (Station SJR34/34A located ~ 1000 m south of Doctors Lake on the west bank) values above the bars indicate the numbers of observations. Solid line (mean), vertical lines (maximum and minimum), and bars (Standard Deviation of the mean). Data source: ***Deuerling 2015****. SJR34/34A mean 8.50 ppt (S.D.±4.53 for the maxima). Note that only one observation was made in 2014.*

With regard to living organisms, changes in water quality parameter averages are not as meaningful as the changes that may occur in the parameter extremes - like salinity maxima and dissolved oxygen minima. If any changes were to persist for an extended time or if they occurred too abruptly then this is likely to be detrimental to survival. Salinity changes may potentially affect the distribution of these fish within estuary creeks and the river by affecting prey distributions for different life stages. As the salinity zone shifts further south, fresh water species are likely to be more impacted than more salt tolerant species.

Red Drum *(Sciaenops ocellatus)*: Red drum is predatory fish that are found in the SJR estuary. The juveniles move into estuary creeks and rivers. Red drum is ecologically in the food web of the St. Johns River where they are bottom feeders that eat crabs, shrimp, worms and small fish. Their predators include larger fish, birds, and turtles. A strong recreational fishery exists, however, drum has not been commercially harvested since 1988.

Spotted Seatrout (*Cynoscion nebulosus*): The spotted seatrout is another bottom-dwelling predator common to estuaries and shallow coastal habitats. It feeds on small fish species such as anchovies, pinfish and menhaden as well as shrimp. Spotted seatrout larvae feed mostly on copepods which are part of the plankton. There are a number of predators that feed on seatrout including Atlantic croakers, cormorants, brown pelicans, bottlenose dolphins, and sharks. These fish have significant commercial and recreational value.

Largemouth Bass *(Micropterus salmoides)*: Largemouth bass are predators in brackish to freshwater habitats in SJR, including lakes and ponds. The young feed on zooplankton, insects and crustaceans including crayfish. Adults feed on a variety of larger fish, crayfish, crabs, frogs, and salamanders. Spawning occurs from December to May, with males constructing nests and guarding young in hard-bottom areas near shorelines. Largemouth bass are aggressive predators, significantly affecting the abundance of many organisms in the area. Bass are a popular game fish in the area supporting fishing tournaments.

Channel & White Catfish (*I. punctatus & A. catus*): Channel and white catfish are omnivorous fish found in freshwater rivers, streams, ponds and lakes. During their lifetime, they may feed on insects, crustaceans (including crayfish), mollusks and fish (**DeMort 1990**). Male will build and guard the nest and fry. Both catfish species are important in benthic food webs that occur in the freshwater sections of the LSJR. Catfish are commercially and recreationally important in SJR.

Striped Mullet (*Mugil cephalus*): Striped mullet are detritivores that can live in a wide salinity range. They are abundant in most of the SJR, closely associated with bottom mud and feeding on algae, and decaying plant material. Mullet spawn offshore and their larvae drift back into the SJR estuary. They help to transfer energy from detrital matter that they feed on to their predators - birds, seatrout, sharks and marine mammals. The commercial mullet fishery has been the largest among all fisheries in the St. Johns for many years with over 100,000 lbs. harvested annually. Additionally, mullet have significant recreational value as food and bait.

Southern Flounder (*Paralichthys lethostigma*): These are another common fish in the SJR estuary that are bottom-dwelling predators that eat shrimp, crabs, snails, bivalves and small fish. After spawning offshore in fall and winter, the larvae drift as part of the plankton eventually being transported back to the estuary to settle and grow. They are important in maintaining ecological balance in their roles as both predator and prey. They are food for sharks, marine mammals and birds. Flounders are important both commercially and recreationally in SJR.

Sheepshead (*Archosargus probatocephalus*): These fish are common to the SJR estuary and coastal waters. They prey on bivalves, crabs and barnacles. The fish spawn off shore in spring and the developing larvae are carried back to the coast by currents. The larvae enter the inlets and settle in shallow grassy areas. These fish are important in maintaining the estuarine and coastal food web as both a predator and prey. Sheepshead are prey for sharks and marine mammals. They are ecologically, recreationally and commercially important.

Atlantic Croaker (*Micropogonias undulatus*): These are bottom-dwelling predators common around rocks and pilings in the estuary. Spawning takes place in winter and spring in offshore waters, and planktonic offspring are transported back inshore to settle in vegetated shallow marsh areas. Croakers are important in the food web as both predator and particularly as prey. They feed on small invertebrates, and are fed on by fish such as red drum, seatrout, and sharks. These fish support significant commercial and recreational fisheries in LSJR.

Baitfish (*multiple species*): There are more than two-dozen small schooling species like anchovies, menhaden, herring, killifish, sheepshead minnows and sardines. Many baitfish species play a vital role in the ecosystem as planktivores. Others eat small crabs, worms, shrimp and fish. Most spawning occurs at inlets or offshore. Most migrate along or away from the shore. When the larvae hatch they are transported back to the estuary where they grow. Baitfish are important as prey for many larger fish species. They are also important as omnivores that recycle plant and/or animal material making that energy available to higher trophic levels. Commercial uses include bait fish such as anchovy, menhaden, sardines, and herring which are converted into fertilizers, fishmeal, oil and pet food (**FWC 2000**). Smaller fisheries catch killifish, sheepshead minnows and sardines.

2.8.4.5. Submerged Aquatic Vegetation (SAV)

Submerged aquatic vegetation provides nursery habitat for a variety of aquatic life, helps to reduce erosion, and limits turbidity by trapping sediment. Sunlight is vital for good growth of submerged grasses. Sunlight penetration may be reduced because of increased turbidity, pollution from upland development and/or disturbance of soils. Deteriorating water quality which may include unusual increases in salinity has been shown to cause a reduction in the amount of viable SAV in an area. This leads to erosion and further deterioration of water quality.

Historical accounts indicate that SAV beds existed in the river since 1773 (Bartram, 1928 - in 1955 Edition). These SAV beds have shown a gradual decline likely due to a number of cumulative impacts including routine dredging, harbor deepening, filling of wetlands, bulk heading and construction of seawalls, water withdrawals, pumping from wells, along with the contributions from chemical contamination, and sediment and nutrient loading that comes from upland development (**DeMort 1990; Dobberfuhl 2007**).

Commonly found SAV species within the salinity transition zone in LSJR include: tape grass (*Vallisneria americana*), wigeon grass (*Ruppia maritime*), and southern naiad (*Najas guadalupensis*). The greatest distribution of SAVs in Duval County is in waters south of the Fuller Warren Bridge (**Kinnaird 1983a**). There are about eight other freshwater species in LSJR (**IFAS 2007; Sagan 2007; USDA 2013**). These species are all likely to be adversely impacted by increases in salinity.

Under controlled laboratory conditions, tape grass has been shown to grow in 0 to 12 parts per thousand (ppt) of salinity and survive for short periods of time in waters with salinities up to 15-20 ppt (**Boustany, et al. 2003; Twilley and Barko 1990**). However, SAV requires more light in a higher salinity environment due to increased metabolic demands (**Dobberfuhl 2007**). Evidence suggests that greater light availability can lessen the impact of high salinity on SAV (**French and Moore 2003; Kraemer, et al. 1999**). What is not clearly understood is the ability of SAV to survive higher salinities when combined with environmental variables like temperature, turbidity and excessive nutrients.

SAV is important ecologically and economically to the LSJRB. SAV persists year round in the LSJRB and forms extensive beds which carry out the ecological role of nursery area for many important invertebrates and fish species, including the endangered Florida manatee (*Trichechus manatus latirostris*) (**White, et al. 2002**). Manatees consume from four to 11% of their body weight in SAV daily (**Bengtson 1981; Best 1981; Burns Jr, et al. 1997; Lomolino 1977**).

Commercial and recreational fisheries, including largemouth bass, catfish, blue crabs and shrimp, are sustained by healthy SAV habitat (Watkins 1995). Fish and insects forage and avoid predation within the cover of the grass beds (**Batzer and Wissinger 1996; Jordan, et al. 1996**). For example, **Jordan 2000** mentioned that SAV beds in the Lower Basin have three times greater fish abundance and 15 times greater invertebrate abundance than do adjacent sand flats.

The section of the St. Johns River north of Palatka had relatively stable trends with normal seasonal fluctuations. The availability of tape grass decreased significantly in the LSJRB during 2000-2001, because the drought caused higher than usual salinity values. In 2003, environmental conditions returned to a more normal rainfall pattern. As a result, lower salinity values favored tape grass growth again. In 2004, salinities were initially higher than in 2003 but decreased significantly after August with the arrival of heavy rainfall associated with four hurricanes that skirted Florida (Hurricanes Charley, Francis, Ivan and Jeanne). Grass beds north of the Buckman Bridge regenerated from 2002-2006 and then declined again in 2007 due to the onset of renewed drought conditions (**White and Pinto 2006a**). **Sagan 2007** notes that one of her monitoring sites, an SAV bed at Sadler Point, the most seaward of all of her monitoring sites, was present in 1998, but after a decline due to drought did not recover as did other SAV beds in the river. She cautions that long term changes in salinity may be stressing SAV in the estuarine portions of the river. Declining SAV in the river south of Palatka and Crescent Lake is highly influenced by runoff and consequent increases in color of the water.

SAV response to drought and/or periods of reduced flow can provide crucial understanding as to how water withdrawals, harbor deepening and/or the issue of future sea level rise will likely affect the health of the ecosystem by adversely altering salinity profiles.

2.8.4.6. Florida Manatee

The Florida manatee (*Trichechus manatus latirostris*) inhabits the waters of the St. Johns River year round. Manatees are generally most abundant in the LSJR from late April through August, with few manatees observed during the winter months (December-February). Manatees are protected under State and Federal Laws: In 1967, under a law that preceded the Endangered Species Act of 1973 the manatee was listed as an endangered species. Manatees are also protected at the Federal level under the Marine Mammal Protection Act of 1972 **Congress 1972b** and at the State level under the Florida Manatee Sanctuary Act of 1978 **FWC 1978**.

Jacksonville University has conducted aerial surveys of manatees from 1994 to 2014. Within the SJR manatees were found in greater numbers south of the Fuller Warren Bridge where their food supply is greatest relative to other areas in Duval County. The SJR provides habitat for the manatee along with supporting tremendous recreational and industrial vessel usage. Watercraft deaths of manatees continue to be the most significant threat to survival. Boat traffic in the river is diverse and includes port facilities for large industrial and commercial shippers, commercial fishing, sport fishing and recreational activity. Also, in order to accommodate larger cargo ships more dredging by the port is expected in the future (Appendix: 2.8. Salinity). Dredging and/or deepening the channel can also affect the salinity conditions in the estuary by causing the salt water wedge to move further upstream (**Sucsy 2008**), negatively impacting biological communities like the tape grass beds on which manatees rely for food (**Twilley and Barko 1990**).

The average numbers of manatees observed on aerial surveys in the salinity transition zone area of the SJR decreased during periods of drought (1994-2000 and 2006-2009) and then increased again after the droughts (2000-2005 and 2009-2012) (Section 4.4). The reason for this was that during droughts elevated salinity leads to demise in the grasses that manatees feed on. As a result manatees leave the study area in search for food. Freshwater withdrawals, in addition to harbor deepening, will alter salinity regimes in the LSJRB; however, it is not known yet by how much. If a sufficient change in salinity regimes occurs, it is likely to cause a die-off of the grass bed food resources for the manatee. This result would decrease carrying capacity of the environment's ability to support manatees.

2.8.4.7. Data Sources & Limitations

Various sources of data were identified from FDEP's STORET database, SJRWMD, USGS and COJ. Monthly data obtained from The City of Jacksonville's Environmental Quality Division "River Run" sampling program was used to determine salinity changes from 1991 to 2014. Other data sources identified include the City's Station List (122 sites) data from 1995-2009; Tributaries (105 sites) data from 1995-2010; The River Run (10 sites) in the main stem of SJR from 1980's to 2014; The Timucuan Run (12 Sites) in the Nassau and Ft. George area sampled every other month dating back to 1997; and the recently established Basin Management Action Plan (BMAP) Tributaries sites updated in October 2010. The latter consists of 10 Tributaries (2-3 sites each) for a total of 30 sites beginning in 2010.

In addition, there is Water Body ID (WBID) trend data available for Jacksonville from 1994-2014. Older data includes Chlorides levels collected at Main Street Bridge from 1954 to 1965 as part of the City's pollution sampling program around the time of the Buckman sewage plant coming on line (**Hendrickson 2014**).

Data obtained from The City of Jacksonville's Environmental Quality Division "River Run" sampling program was used to determine salinity changes from 1991 – 2014. Data is collected about twice a month at the surface (0.5 m), middle (3-5 m), and bottom (5-10 m) in the water column. Four sites were chosen from the regular ten sampling stations.

1) *West bank of SJR 1000m south of Doctors Lake;*
2) *East bank of SJR 200m north of a large apartment complex near Jacksonville University;*
3) *South bank of SJR just west of Dames Point Bridge, near the western most range marker.*
4) *Main stem of SJR Mid channel N. of Piney Pt. 100 m west of green marker 5.*

Kendall's Tau correlation analysis revealed that salinity over time had significantly increased at the bottom, middle and surface at SJR near Doctors Lake, Piney Point mid-river, near Jacksonville University and Dames Point Bridge. For a map of the sample sites, analysis results and graphs showing these trends see Figures 8-20 in Appendix: 4.1.7.1.F. Salinity.

Monthly data are limited in that the sampling frequency is relatively low and short term events in weather may not be well represented. Continuous water quality data are available on the web through the USGS (**USGS 2015a**)(Update USGS 2015). Currently active stations include the Dames Point Bridge, Buckman Bridge (Figure 2.77), and Dancy Point. Other non-active stations for which data is available include Main Street Bridge and Shands Bridge. Yet another new source for continuous data in LSJR includes NOAA's PORTS program (**NOAA 2015b**). This data has some gap years due to budget cuts preventing collection. Data at Buckman Bridge show an increasing salinity trend in salinity maxima from 1995-2002 (represents a period of drought) then no data was available from 2003-2007, followed by a slightly downward trend from 2008-2015 (represents a period of more normal rainfall from 2013-2015). However, it is evident that large salinity fluctuations occurred and persisted for some time.

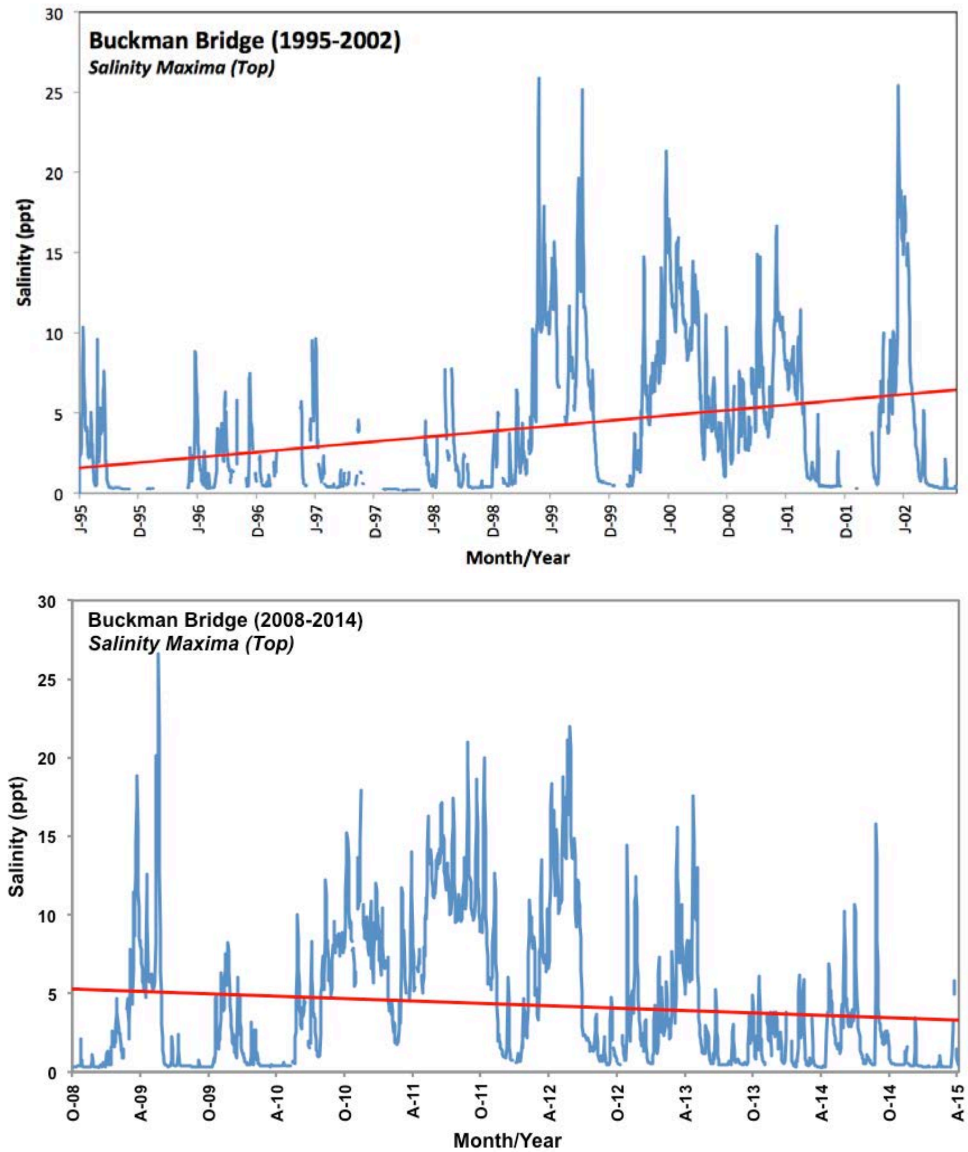


Figure 2.77. Salinity maxima for 1995-2002 and 2008-2015 from USGS continuous data recording station at Buckman Bridge.

Rainfall distributions in Northeast Florida can be divided into two seasons: A wet season spanning five months (June-October) which receives about 60% of the annual rainfall, and a Dry Season of seven months (November-May). In addition, the wet season is warm (June-September) and the dry season is cold (December-March).

Daily rainfall data is sporadic both in quantity, location and duration. Quite often in warm weather, short shower rain may not reach the surface of the ground because of evaporation. Monthly rainfall data also shows significant variation (Appendix: 4.1.7.1.E.). Increasing rainfall over time is followed by a decrease in the salinity of river water, and vice versa, as rainfall decreases (exacerbated during a drought) the relative salinity of river water tends to be more elevated.

The actual duration of rain events (continuous rainy days) or lack of them (drought period) and how that relates to the duration of increased or decreased salinity relative to the normal condition at various locations and times in the LSJR is not well understood. A variable time delay exists in the response of the salinity in the LSJRB to rainfall conditions. Furthermore, the effects of salinity exposure and duration on biological flora and fauna are also poorly understood.

Rainfall can be affected by larger global scale weather events such as El Niño and La Niña that also influence where hurricanes develop in the Atlantic (Appendix: 4.1.7.1.E.). During El Niño fewer hurricanes and major hurricanes develop in the deep Tropics off western Africa. During La Niña more hurricanes form off the western African coast, and these systems have greater potential for developing into major hurricanes that could impact the U.S. and Caribbean region. The probability for the continental U.S. and the Caribbean Islands to experience a hurricane increases during La Niña, and decreases during El Niño (**NOAA 2015a**).

Also, long term anthropogenic effects like the large scale draining of wetlands for development and farming could lead to decreased rainfall in the summer and more severe freezes during the cold season (**Marshall, et al. 2004a; Marshall, et al. 2004b**). Another characteristic of the environment in Northeast Florida is that there exists a natural and somewhat unpredictable cycle of periodic droughts which has far reaching effects on the ecosystem (Appendix: 4.1.7.1.E.). More recently, a number of these factors have had a cumulative effect in the way they impact the ecology of the LSJRB. The late 1990's experienced a period of declining rainfall which was one of the worse drought periods in Florida history. The effect of El Niño (1997 – 1998) was the severest to date which had the effect of exacerbating drought conditions more. Then, from 2000-2005 rainfall gradually increased on an annual basis again. In 2006, rainfall decreased abruptly and was followed by a shorter period of drought before increasing again in 2007-2008. The normal average monthly rainfall for the period 1951-1960 was 4.32 inches (**Rao, et al. 1989**), and was similar for the period 1995-2013 (4.09 inches). Additional data on rainfall is contained in Appendix: 4.1.7.1.E. Rainfall, Hurricanes, and El Nino.

Sea level rise is another factor likely to affect the St. Johns and about which more information regarding potential impacts is needed. In addition, any repositioning of point sources can alter pollution loading to the St. Johns River and should be monitored for any potential impacts to the local ecology. Moreover, the cumulative effects of freshwater withdrawals on flora and fauna should be monitored to assess the impacts of water supply policy (**NRC 2011**). Bellino and Spechler (**Bellino and Spechler 2013**) mentioned that dredging will have little or no effect on groundwater salinity, although dredging activities are expected to alter river salinity along the entire navigation channel, even in upstream locations that are not a part of the current dredging plans. Major dredging events that deepened the channel occurred in 2003 (mouth of SJR to river mile 14.7) and 2010 (river mile 14.7 to 20). The channel was deepened by 2 ft. from 38 ft. to 40 ft. In 2003, there appears to have been a salinity increase in the river likely associated with this event in spite of adequate rainfall that year. However, in 2010 low rainfall lead to a drought, which likely caused salinity to increase significantly more than in 2003.

2.8.4.8. Wetlands

Based on the modeling results of the SJRWMD Water Supply Impact Study in February 2012, segments within the LSJRB are expected to experience a change in annual mean salinity, which would, in turn, affect wetland communities. The likelihood of salinity effects to saltmarsh species would be minimal. These species can tolerate salinity increases without negative impacts. However, the area of greatest concern between the Fuller Warren Bridge and the Shands Bridge, is dominated by hardwood swamps and extensive areas of freshwater and transitional vegetation. In these areas, salinity effects are likely to be most significant. The category of wetlands most negatively impacted are "freshwater marshes" and these are likely to be most affected by rising sea level, and the cumulative impacts associated with withdrawals over time (**SJRWMD 2012a**). Vegetation boundaries are predicted to move upstream by up to 1.13 km in the Ortega River. Thus, certain types of wetland communities will be negatively impacted by future surface water withdrawals in the St. Johns River. These impacts must be considered cumulatively with other expected impacts from future changes in land use, surface water runoff, rainfall, navigational works, groundwater, and sea level rise.

2.8.4.9. Dissolved oxygen

Salinity is one of many factors that affect DO concentrations in the LSJRB. Salt reduces oxygen solubility causing lower DO in aquatic systems. Normal seawater has about 20% less oxygen than freshwater (**Green and Carritt 1967; Weiss**

1970). Factors influencing DO, such as increasing temperatures and Biological Oxygen Demand (BOD), will be compounded in saltwater as compared to freshwater.

2.8.4.10. Algae blooms

Growth rates of cyanobacteria and species distribution in an ecosystem are highly dependent upon light, temperature, and salinity. Many of the more recent toxic algae blooms in LSJR have occurred in the freshwater sections. These blooms have also persisted for some time in the marine section only because of increased precipitation which lowered the salinity and thus allowed them to survive. Increased salinity in the SJR system may cause there to be a shift towards more marine types of algae again depending on the levels of nutrients available and the temperature. In addition, some of these may be toxic (like red tides and brown algae blooms) or non-toxic “super blooms” such as those seen in the Indian River Lagoon in the past few years (**Gobler and Sunda 2012; Lapointe, et al. 2015**).

2.8.4.11. Contaminants

Salinity may affect the toxicity of some metals to aquatic life and therefore the EPA class III Water Quality Criterion (WQC) values are often different for freshwater and marine water. For freshwater, hardness, defined as the total concentration of the divalent cations calcium and magnesium, has also been shown to reduce the toxicity of the metals cadmium, copper, lead, nickel, and zinc.

Finally, salinity changes in LSJRB will likely affect the deposition rate of sediments within the estuary and tributaries and therefore dredging and maintenance of waterways for navigation. This is an area of research for which more information is needed. When more dense salt water meets less dense freshwater this can result in the flocculation and deposition of suspended material that can alter sediment accumulation rates and locations.

3. Fisheries

Photo: G. F. Pinto

3.1. Introduction

3.1.1. General Description

The LSJRB supports a diverse fin fish and invertebrate community that has significant commercial and recreational value. Blue crabs account for the majority of landings comprising 73% of the total landings for 2013 (**FWRI 2015b**). Commercial fin fish accounted for about 26% of the total catch predominantly striped (black) mullet (19%); flounders and menhaden (2%); followed by sheepshead; croakers; seatrout and catfish. The oyster harvest represented about 2% of the total weight harvested in 2013 (Figure 3.1). Recreationally, the St. Johns River area supports high numbers of red drum, spotted seatrout, croaker, sheepshead, flounder, largemouth bass and bluegill that are sought by both local and visiting anglers.

3.1.2. Data Sources & Limitations

All available literature was used to examine potential long-term trends (1955-2014) in fish communities via the presence or absence of species encountered in the particular study. Although, such comparisons can give insight into whether the overall fish community was the same for the time periods compared, a major weakness of this comparison is that it gives no information on how the numbers of a given species may change with time. Also, the collection methods in these studies were not the same thus making it difficult to draw valid conclusions.

Two data sources were provided by the Florida Fish and Wildlife Research Institute (FWRI) as follows: 1) Commercial fisheries landings reports (1994-2014), and 2) data from the Fisheries Independent Monitoring (FIM) program (**FWRI 2002; FWRI 2003; FWRI 2004; FWRI 2005; FWRI 2006; FWRI 2007; FWRI 2008d; FWRI 2009; FWRI 2010; FWRI 2011; FWRI 2012a; FWRI 2013a; FWRI 2014a**). For commercial landings data, there are uncertainties associated with either the exact location of where a fish was caught and/or the method of estimating total number of landings for a given area. In particular, these data do not differentiate between fish and invertebrates caught in the LSJR or the ICW. In addition, changes in fishery regulations over time limit what can be said of landings between certain time periods. For the most part, the total landings have been graphed. To best standardize comparisons of the total landings over time, we calculated landings per trip, and trends were investigated using a Kendal-Tau correlation analysis. It is important to note that the 2014 data are preliminary and 2013 data are finalized.

The most statistically reliable data used in this report comes from ongoing research conducted by the FWRI-FIM program (See Appendix 3.1.1 for river areas sampled). Data are presented in two forms. The first form displays for each species yearly indices of abundance for three age classes (young of the year, juveniles, and sub-adults/adults) encountered within the lower basin of the river. The second form displays the monthly length frequency diagrams for each species for the 13-year sampling period. Both forms of display allow for more specific insight into temporal trends. Potential trends in all these data are investigated using Kendal-Tau correlation analysis. Finally, scientific literature was used where appropriate to supplement these data, and form our conclusions on trends and status.

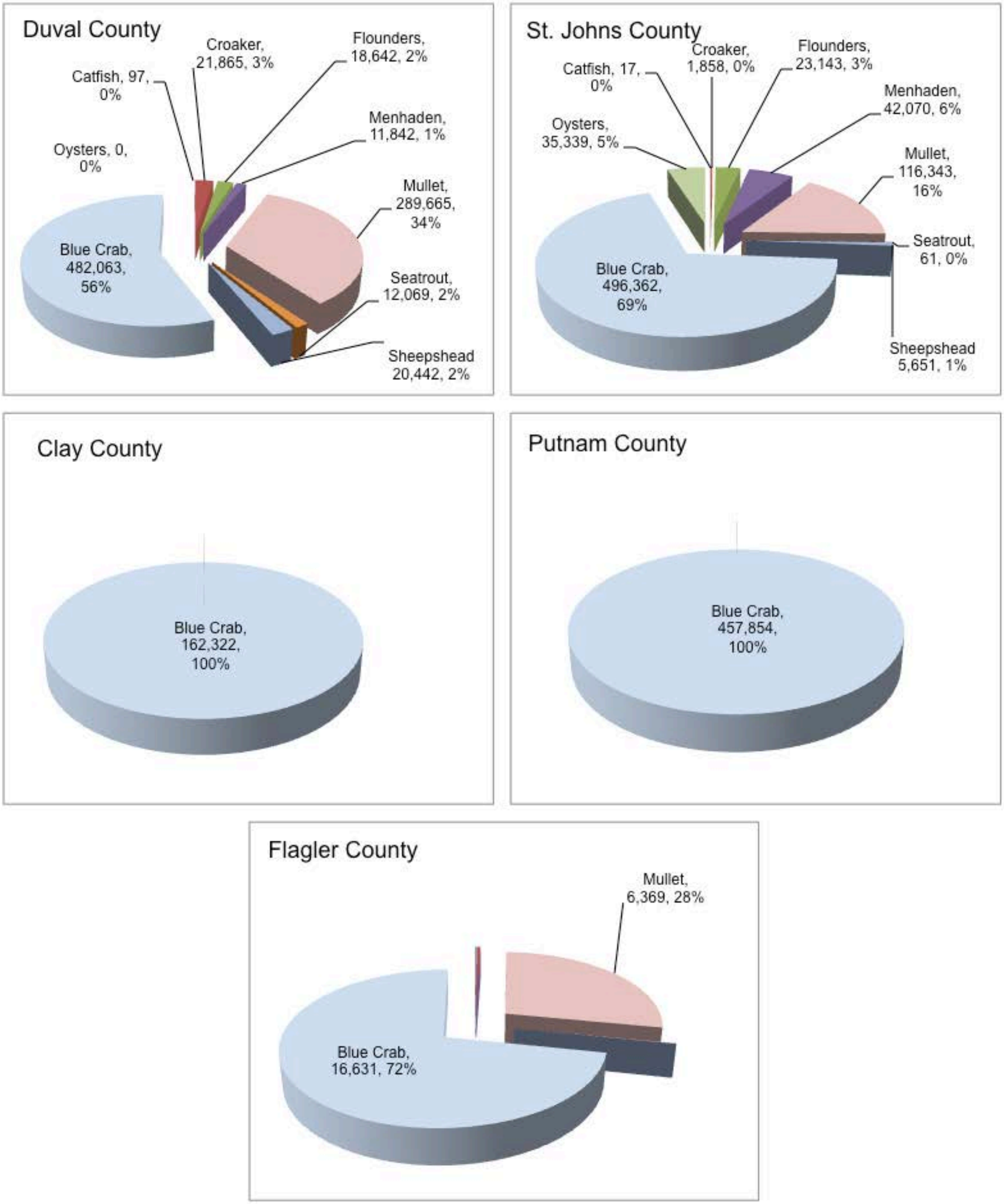
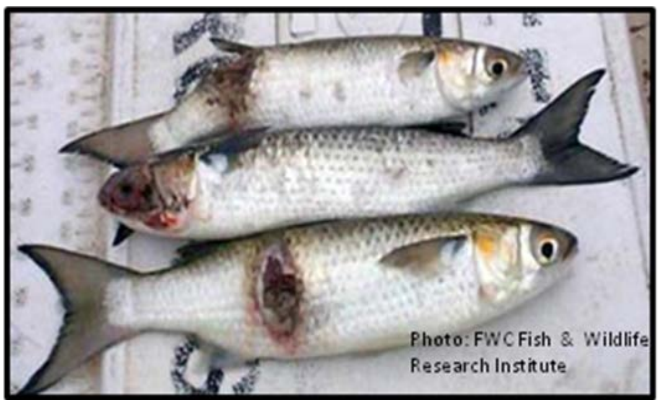


Figure 3.1. Percent comparison of commercially important fish and invertebrates caught by fisherman of five counties associated with the lower basin of the St. Johns River in 2013. These data do not differentiate between fish and invertebrates caught in the St. Johns River or the Intracoastal Waterway (ICW).

3.1.3. Health of Fish and Invertebrates

There is not much information on the health of fish and invertebrates from the LSJRB. In the mid-1980s, there were concerns with fish health in the St. Johns River when high numbers of fish with external lesions (called Ulcerative Disease Syndrome - UDS) were reported by local fishermen. A comprehensive 1987 study (**CSA 1988**) from Clapboard Creek to Lake George revealed only 73 lesioned fish out of 69,510 (0.11%). However, this study also observed a higher percentage (5%) of lesioned fish in the Talleyrand area with the main affected fish being southern flounder, weakfish, yellowfin, menhaden, southern stingray and Atlantic croaker. FWRI has data for the LSJR and the *Aphanomyces* fungus – published in part in **Sosa, et al. 2007**. The latter study comprised of a statewide and historical survey of *Aphanomyces* and associated ulcerative lesions in fish. In the SJR, a number of species were confirmed with ulcerative lesions from *Aphanomyces* between 1980-2003 (time of study and retrospective analyses) including striped mullet (*Mugil cephalus*), Gulf flounder (*Paralichthys albigutta*), menhaden (*Brevoortia* sp.), weakfish (*Cynoscion regalis*), southern flounder (*Paralichthys lethostigma*), gray snapper (*Lutjanus griseus*), Atlantic croaker (*Micropogonias undulatus*), hickory shad (*Alosa mediocris*), American shad (*Alosa sapidissima*), brown bullhead (*Ameiurus nebulosus*), silver perch (*Bairdiella chrysoura*), pinfish (*Lagodon rhomboides*), sand seatrout (*Cynoscion arenarius*), and sheepshead (*Archosargus probatocephalus*). FWRI research suggested that a major cause of the lesions is a water mold (*Aphanomyces invadans*) that is more likely to infect stressed fish. Fish can be stressed when exposed to unusual changes in salinity, temperature and water quality.



During the summer and fall of 2010, there was a sequence of unusual events in the LSJR involving extensive fish kills, cyanobacteria blooms, foam formation and bottlenose dolphin deaths. From late May until July 2010, there were extensive fish kills within the St. Johns River from Lake George to the downtown Jacksonville area. The mortality event lasted much longer than mortality events caused from hypoxia. While multiple species of dead fish were observed, white catfish, red drum, longnose gar, Atlantic stingrays, and menhaden were reported to be most affected by the event. Generally, most observed dead fish did not have lesions or sores. Co-occurring with the fish kill were cyanobacteria blooms of *Aphanizomenon cf. flos-aquae* followed by blooms of other algal species. Fish histopathology suggested that cyanobacteria-degrading bacteria may have played a role in this fish mortality event. During mid-October, a second, less widespread fish mortality event occurred in the river in which smaller fish, mostly menhaden, were found with lesions near the caudal fin. This later fish kill may have been because of a bloom the fungus *Aphanomyces invadans (**Sosa, et al. 2007**)*.

FWRI has investigated external abnormalities such as lesions in fish since 2000. They surveyed fish and invertebrates for the presence of abnormal growths, colors and ulcers or gross external abnormalities (GEA). They also sampled mercury levels in muscle tissue from the shoulder area in similar sized (generally larger) spotted seatrout, red drum, southern flounder, southern kingfish (whiting), and blue crabs.

The incidence of GEAs was found to be less than one percent from 2001 to 2010 (**FWRI 2002; FWRI 2003; FWRI 2004; FWRI 2005; FWRI 2006; FWRI 2007; FWRI 2008d; FWRI 2009; FWRI 2010; FWRI 2011**). During this time period, the percent of fish affected by GEAs has varied between 0.001 to 0.4 % (Figure 3.2). While 26 species of fish with GEAs have been encountered by FWRI from 2001 to 2010, the most commonly observed fish with GEAs during this time period are striped mullet, menhaden, sheepshead, and largemouth bass.

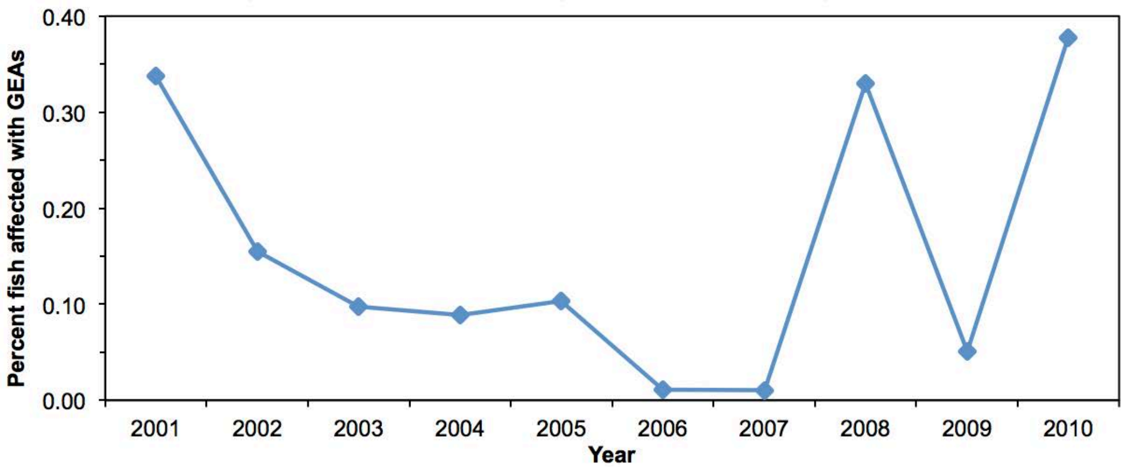


Figure 3.2. The percent of fish encountered with gross external abnormalities (GEAs) for each year of the ongoing FWRI study. A Kendall tau correlation revealed no significant trend over time (τ=-0.400; Not statistically significant) in the percent fish encountered with GEAs from 2001 to 2010.

Mercury has been detected in a number of freshwater, estuarine and marine species in the state of Florida. The Florida Department of Health (FDOH) issues consumption advisories for a number of marine and estuarine fish (**FDOH 2015**). Generally, these are large, long-lived predatory species which bioaccumulate high concentrations of mercury, over their lifetimes. Consumption advisories recommend the amount of the affected fish species that can safely be eaten in a given time span. It is recommended that fish that exceed a concentration of 1.5 parts per million (ppm) of mercury not be eaten by anyone. The general population can still eat fish with a 0.3 ppm mercury concentration although there are more limiting human consumption advisories for children and women of child-bearing age (sensitive populations) when concentrations in fish exceed 0.1 ppm (**Goff 2010**).

In the LSJR, the FDOH advises limited consumption (1-8 meals per month---depends on the species) of Atlantic croaker, Atlantic thread herring, Atlantic weakfish, black drum, brown bullhead, redbreast sunfish, bluegill, black crappie, gulf and southern flounder, jack crevalle, hardhead catfish, red drum, sand seatrout, sheepshead, spotted seatrout, southern kingfish, striped and white mullet, spot, warmouth, largemouth bass, bowfin, and/or gar. Everyone is advised to eat no king mackerel larger than 31 inches, and no sharks larger than 43 inches (**FDOH 2015**). Note that more restricted consumption is recommended for children and pregnant/lactating women. For more information about consuming fish, see the FDOH website (**FDOH 2015**). For more information about mercury in fish and other species, see Section 5.4.4.

3.2. Finfish Fishery

3.2.1. General description

The LSJRB supports a fish community of great ecological, commercial and recreational value to the public. Most of the fish sought after are predaceous fish that are important in maintaining community balance in the areas where they occur. Historically, American eels and shad were huge fisheries in the St. Johns, although populations have decreased to such low levels that they are now not the focus of most commercial fisherman (**McBride 2000**). Currently, the premier commercially harvested estuarine or marine fish in the lower basin are striped mullet, flounder, sheepshead, menhaden, black drum, croaker and whiting. However, American eels, spotted seatrout, and weakfish are also commercially harvested. In freshwater sections of the river, important species commercially harvested include catfish, gar, bluegill/redear sunfish, shad, American eels, and non-native tilapia. Of the five counties studied, Duval County had the overall highest landings (over 374,622 lbs. in 2013), and the most fish species caught per year (only includes fish caught within the river and ICW). Furthermore, Duval County ranks second largest among Florida counties in seafood harvested, predominantly shrimp caught in off shore coastal waters (**DACS 2014**).

The St. Johns River supports a diverse recreational fishery in the lower basin. Within the different sections of the river, significant fisheries exist for freshwater, estuarine or saltwater fish. Popular saltwater species sought after are red drum, spotted seatrout, flounder and sheepshead. Premier freshwater species include largemouth bass, blue gill and catfish. The abundance of some of these fish species in the river has resulted in a number of very high profile fishing tournaments occurring each year - red drum and bass tournaments being among the most popular.

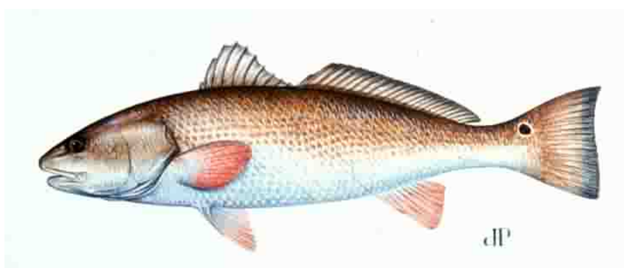
3.2.2. Long-term trends

For many years, humans have benefited from the thriving fish communities that utilize the LSJR. Indeed, a number of the species sought after today, such as spotted seatrout and sheepshead, were commented on by the naturalist William Bartram as far back as the late 1700s. However, despite the importance of river fisheries over the years, only a few studies have rigorously sampled fish populations in the SJR. In response to this need for more information, the FWRI started a monthly fish-sampling program in 2001 that is designed to understand fish population changes with time in estuarine areas of Northeast Florida.

The available long-term research suggests that many of the same species present today (~170 species total) were present in the river back in the late 1960s (**McLane 1955**; **Tagatz 1968c**; **FWRI 2008d**). However, it is unclear whether the numbers of individual species have changed during this time period because of different sampling methods used in these studies. Currently, the most numerically dominant species in the lower basin include anchovy, striped mullet, killifish, menhaden, Atlantic croaker, spot, silversides, and silver perch.

A preliminary study by L. McCloud with SJRWMD (**McCloud 2010**) compared current FWRI fish data with those collected by Tagatz in 1968 (**Tagatz 1968c**). Her research suggested that at some areas of the river, observed fish communities were 50% different between 1968 and the 2001-2006 time period. She further suggests that the observed differences in fish communities in these areas may have been the result of a transition zone between marine and freshwater moving further upstream. One of the unique aspects of the St. Johns Estuary is the ability of some marine fish to ascend far upstream into freshwater. For instance, stingrays are abundant in a number of freshwater areas in the river. However, most fish are sensitive to their environment, and can move from an area in response to unsuitable changes in important environmental factors such salinity, dissolved oxygen, and temperature.

3.2.3. Red Drum (Sciaenops ocellatus)



http://myfwc.com/marine/fish/reddrum.jpg

3.2.3.1. General Life History

Red drum (also called puppy drum, channel bass, spottail bass, red bass and redfish (**FWRI 2014b**) are predatory fish that are found in the estuarine sections of the St. Johns River. During the fall and winter, they spawn at dusk in coastal waters near passes, inlets and bays. Newly hatched young live in the water column for 20 days before settling to the sea floor bottom where they will develop into juveniles that live within estuary creeks and rivers. Young fish will become reproductively mature fish at around three years of age, and may ultimately live for approximately 40 years (**Murphy and Taylor 1990**), and reach a maximum length of five feet.

3.2.3.2. Significance

Red drum are ecologically important as both a predator and prey in the food web of the St. Johns River. They are bottom feeders that eat crabs, shrimp, worms and small fish. Their predators include larger fish, birds, and turtles.

A strong recreational fishery exists for red drum. The recreational fishery for red drum is an estuarine and near-shore fishery, targeting small, "puppy drum" and large trophy fish. Trophy-size fish are caught along the mid- and south coastal barrier islands, while smaller red drum are taken in shallow estuarine waters. Red drum has not been commercially harvested since 1988 to minimize impacts to natural populations.

3.2.3.3. Trend

The FWRI data set shows consistent trends in abundance from 2001 to 2013 (Figure 3.3). Kendall tau correlation analyses revealed no temporal trend in number per set for young of the year (τ =0.077; N.S.), juvenile (τ =-0.256; N.S.) nor subadults/adults (τ =-0.179; N.S.). Young of the year appear in the river in September and become juveniles in approximately one year (Appendix 3.2.3a).

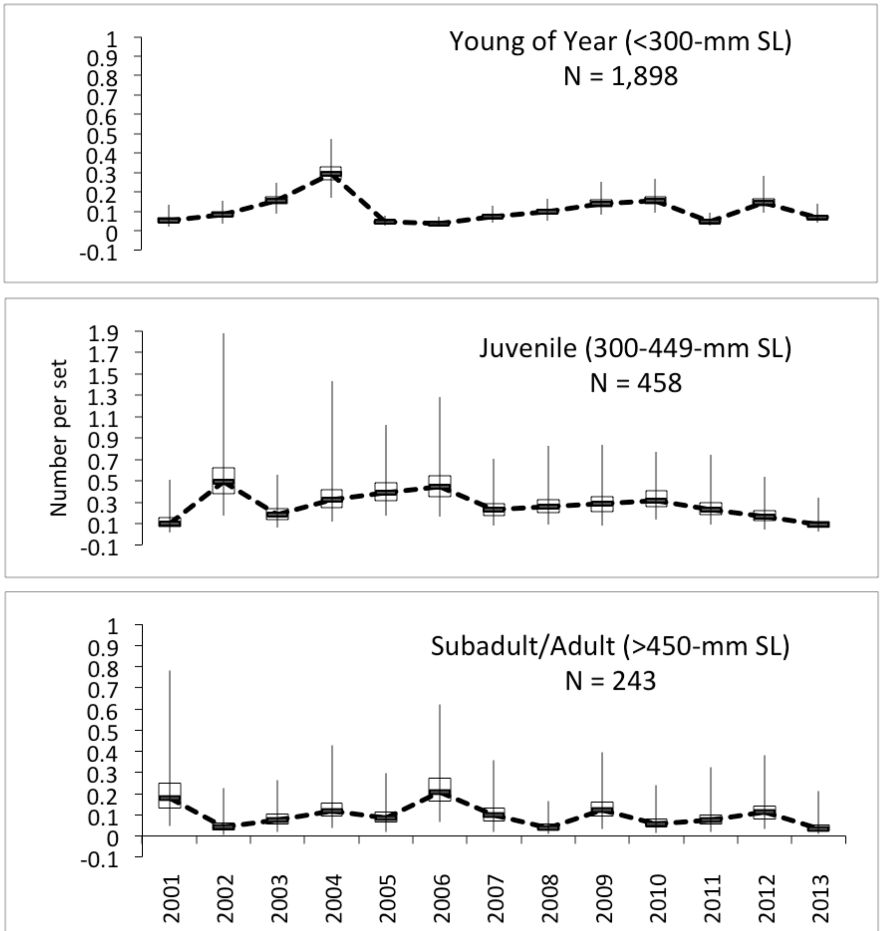


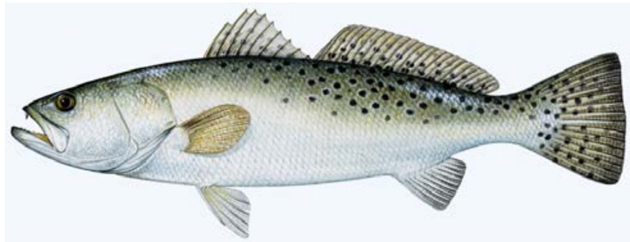
*Figure 3.3. Number of young of the year, juveniles, and subadults/adults of red drum caught within the lower basin of the St. Johns River from 2001-2013. The N value indicates the total number of sets completed for the time period (**FWRI 2014a**).*

3.2.3.4. Current Status and Future Outlook

Red drum represent an important recreational fishery in the LSJR and appear to be safe from overexploitation (**Murphy and Munyandorero 2008**). There is concern that increased fishing activity in the future may cause decreases in fish numbers through direct loss of fish captured, and mortality of “returned” fish. Consequently, close monitoring of reproduction and abundance in local populations is essential for ensuring the long-term maintenance of red drum in LSJRB. Taking everything into account, the current STATUS of Red Drum is *satisfactory*, and the TREND is *unchanged*.

Recreationally, a maximum of two red drum may be caught per person per day throughout the year. Individual fish must be between 18 and 27 inches in length and no red drum may be sold for profit (**FWC 2015c**).

3.2.4. Spotted Seatrout (Cynoscion nebulosus)



http://www.floridasportfishing.com/magazine/images

3.2.4.1. General Life History

The spotted seatrout is a bottom-dwelling predator that is common in estuarine and shallow coastal habitats in Northeast Florida. It is a carnivore that preys on a number of small fish species such as anchovies, pinfish and menhaden. Reproduction tends to occur during the night within the river from spring through fall with a peak during April through July. The young often form schools of up to 30-50 individuals. Individual fish will become sexually mature in 2-3 years. Their expected lifespan is 8-10 years. They may reach a maximum length of three feet.

3.2.4.2. Significance

Spotted seatrout are very important in both the benthic and planktonic food webs in the St. Johns. As newly hatched young they are planktivores, feeding primarily on copepods within the plankton. As they grow, they shift to larger prey including shrimp, and eventually a number of smaller fish within the river. A number of predators feed on seatrout including Atlantic croaker, cormorants, brown pelicans, bottlenose dolphin, and sharks.

There are recreational and commercial spotted seatrout fisheries within the St. Johns River. Recreationally, the fish is the premier game fish in the area for visiting and local anglers. Annual commercial landings for the state of Florida were over 4 million lbs. in the 1950s and 1960s, and down to 45,000 lbs. in 2006 (**Murphy, et al. 2011**). Out of this value, the LSJR (and the neighboring ICW) accounts for approximately 5,000 lbs. harvested annually. Reductions in landings since the 1950s and 1960 have been in large part due to more stringent fishing regulations.

3.2.4.3. Trend

Commercial landings decreased substantially in the mid-1980s and again in the mid-1990s (Figure 3.4; Appendix 3.2.4a). However, landings have generally remained variable but consistent for the whole river since 1996 (Appendix 3.2.4a). The substantial mid-1990s decrease may be due to the impact of the gill net ban (**Murphy, et al. 2011**). The FWRI data set shows consistent trends in abundance from 2001 to 2014 (Figure 3.5). Kendall tau correlation analyses revealed no temporal trend in number per set for young of the year (τ =-0.061; N.S.), juvenile (τ =0.055; N.S.) nor subadults/adults (τ =0.111; N.S.). However, there was a small peak in the number of young of the year (<91 mm) caught in 2007. Young of the year appear in the river in May and become juveniles within one year (Appendix 3.2.4b).

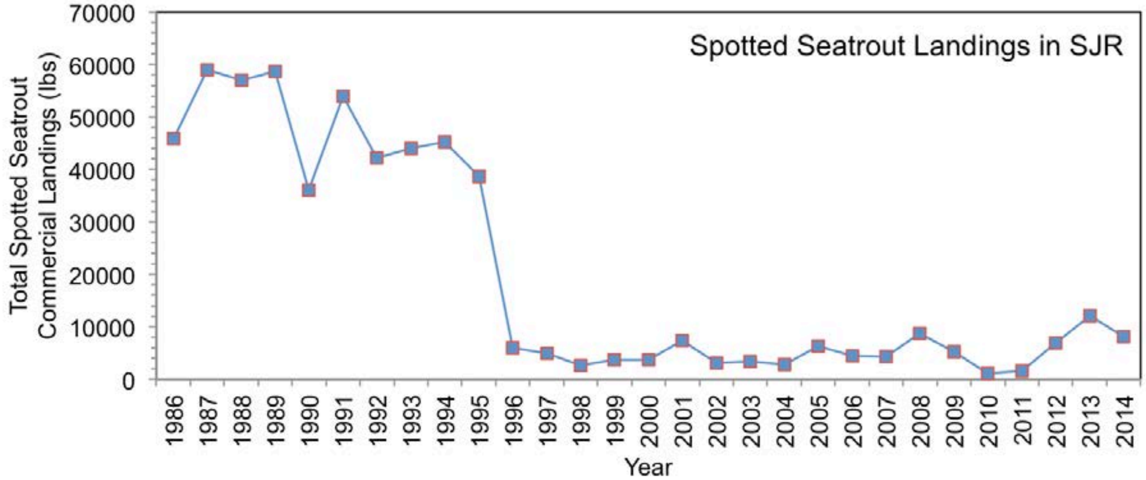


*Figure 3.4. Commercial landings (in lbs.) of spotted seatrout within the lower basin of the St. Johns River from 1986 to 2014. Note that gill nets were banned in 1995. (**FWRI 2015b**)*

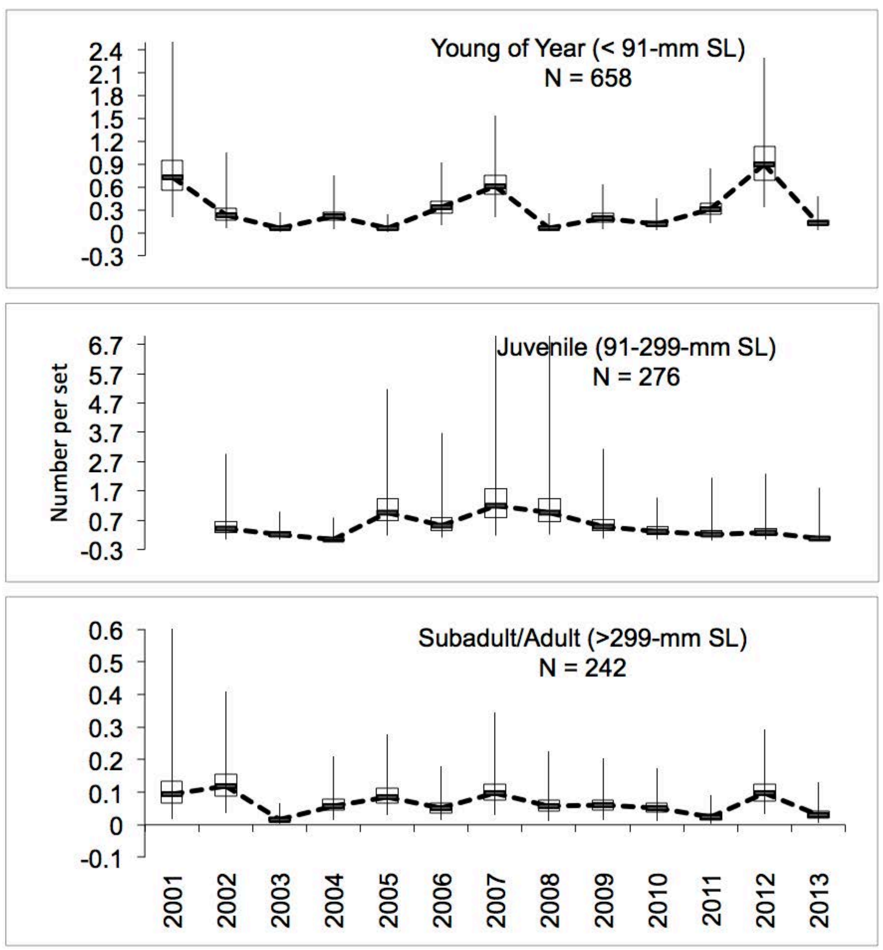


*Figure 3.5. Number of young of the year, juveniles, and subadults/adults of spotted seatrout caught within the lower basin of the St. Johns River from 2001-2013. The N value indicates the total number of sets completed for the time period. (**FWRI 2014a**)*

3.2.4.4. Current Status & Future Outlook

The spotted seatrout recreational fishery has grown in the last 15 years while the commercial fishery has remained somewhat stable. There has been concern that there could be a decrease in landings with time that may be related to: 1) changes in fishing regulations, 2) coastal development, and 3) fishing pressure (**Murphy, et al. 2011**). Despite this concern, a recent FWRI stock assessment suggests that spotted seatrout are not being overfished within the Northeast

Florida region (**Murphy, et al. 2011**). Taking everything into account, the current STATUS of Spotted Seatrout is *satisfactory*, and the TREND is *unchanged*.

Recreationally, spotted seatrout are considered a restricted species (**Murphy, et al. 2011**). However, they can be caught all months of the year. The legal size range is 15 to 20 inches (slot limit) with a daily limit of six per person and each person is allowed to keep one fish (included in the daily bag limit) that exceeds the slot limit of 20 inches. The season is open year round. (**FWC 2015c**).

3.2.5. Largemouth Bass (Micropterus salmoides)

http://www.usbr.gov/.../activities_largemouth_bass.jpg

3.2.5.1. General Life History

Largemouth bass are predatory fish that occupy shallow brackish to freshwater habitats, including upper estuaries, rivers, ponds and lakes. When young, they are carnivores feeding on zooplankton, insects and crustaceans including crayfish. As they get older, they feed on a variety of organisms such as larger fish, crayfish, crabs, frogs, and salamanders. They reproduce from December through May (**FWC 2015b**). The male builds nests in hard-bottom areas along shallow shorelines. The female then lays her eggs in the nest, where they are fertilized as they enter the nest. The male will guard the nest, and later, the young fry. The fry initially swim in tight schools, and then disperse when they reach about one inch in size. Largemouth bass may live up to 16 years growing in excess of 22 inches in length.

3.2.5.2. Significance

Largemouth bass are very important in freshwater benthic food webs in the lower St. Johns River. Their willingness and aggressiveness to feed on any appropriately sized prey is significant in affecting the abundance of many organisms in the same habitat. Recreationally, bass are a popular game fish in the area for visiting and local anglers.

3.2.5.3. Trend

FWRI research in the past 12 years shows fairly similar yearly abundances from 2001 to 2013 (Figure 3.6). Kendall tau correlation analyses revealed no temporal trend in number per set for young of the year (τ =-0.256; N.S.), juvenile (τ =-0.026; N.S.), however, there was a positive correlation among subadults/adults (τ =0.359; 0.04). Young of the year appear in the river in April and become juveniles within one year (Appendix 3.2.5a).

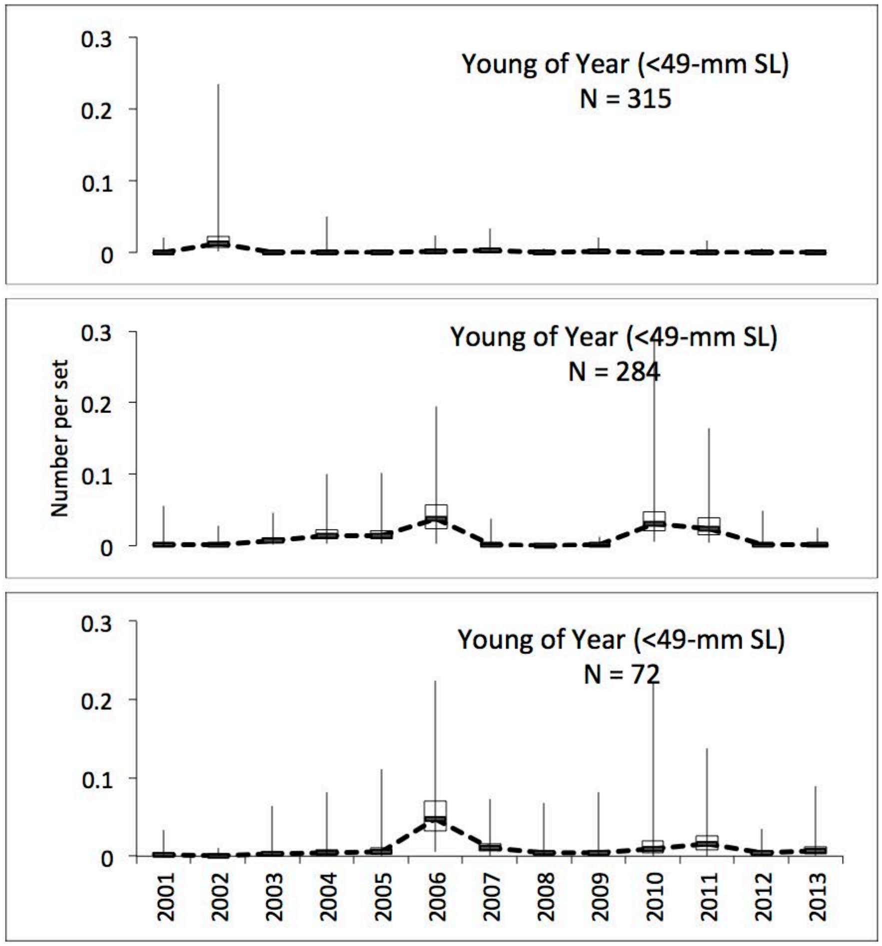


*Figure 3.6. Number of young of the year, juveniles, and subadults/adults of largemouth bass caught within the lower basin of the St. Johns River from 2001-2013. The N value indicates the total number of sets completed for the time period. (**FWRI 2014a**)*

3.2.5.4. Current Status & Future Outlook

There is not enough information to assess the status of the recreational fishery associated with largemouth bass in the lower St. Johns River. However, they are not likely to be overfished in the near future. Bass are commonly raised in hatcheries and stocked in lakes and ponds throughout Florida. Taking everything into account, the current STATUS of Largemouth Bass is *uncertain*, and the TREND is *unchanged*.

Recreational fishermen are permitted to take largemouth bass all months of the year. A daily limit of five per person is allowed with minimum size of 14 inches and only one of the five being more than 22 inches (**FWC 2015c**).

3.2.6. Channel & White Catfish (Ictalurus punctatus & Ameiurus catus)

http://myfwc.com/.../images/raverart/White-Catfish.jpg

3.2.6.1. General Life History

Channel and white catfish are omnivorous fish that can be found in primarily freshwater rivers, streams, ponds and lakes. During their lifetime, they may feed on insects, crustaceans (including crayfish), mollusks and fish. They reproduce in the river in the spring and summer months. The male builds nests where the female lays the eggs and fertilization occurs. The male will guard the nest and later the young fry. The fry will leave the nest one week after hatching. As they mature, catfish will tend to occupy bottom areas with slow moving currents. Individuals may live 11-14 years.

3.2.6.2. Significance

Both catfish species are very important in benthic food webs in the more freshwater sections of the LSJR. They are abundant, and feed on a wide variety of organisms during their lifetime (**DeMort 1990**). They are a major component of the freshwater commercial fishery in Florida. There is also a large recreational catfish fishery within the river. Channel catfish are often stocked in ponds and lakes to maintain population numbers.

3.2.6.3. Trend

Commercial landings of catfish decreased substantially in the mid-1990s (Figure 3.7). This mid-1990s decrease may be due to the impact of the Florida gill net ban. Since this time period, landings have been decreasing in the north (landings mostly likely from tributaries in this area) sections of the river (Appendix 3.2.6a). The FWRI data set shows variable but consistent trends in abundance for both the channel and white catfish from 2001 to 2014 (Figures 3.8 and 3.9). Kendall tau correlation analyses revealed negative correlations over this time period for channel catfish in number per set for young of the year (τ =-0.384; p=0.034; n=13), juvenile (τ =-0.157; N.S; n=13) and subadults/adults (τ =-0.485; p=0.014; n=12). However, there did appear to be a decrease in subadult/adult abundance from 2001-2005 before numbers started to become relatively similar (Figure 3.8). While somewhat variable, young of the year of this species appear in the river in June and become juveniles in approximately one year (Appendix 3.2.6b). In terms of white catfish, there were also no trends observed in number per set for young of the year (τ =-0.186; N.S.), juvenile (τ =-0.154; N.S.) nor subadults/adults (τ =0.103; N.S.). However, the temporal patterns were particularly variable for young of the year with peaks encountered during 2003 and 2006. While also fairly variable, young of the year appear in the river in June and become juveniles in approximately one year (Appendix 3.2.6c).

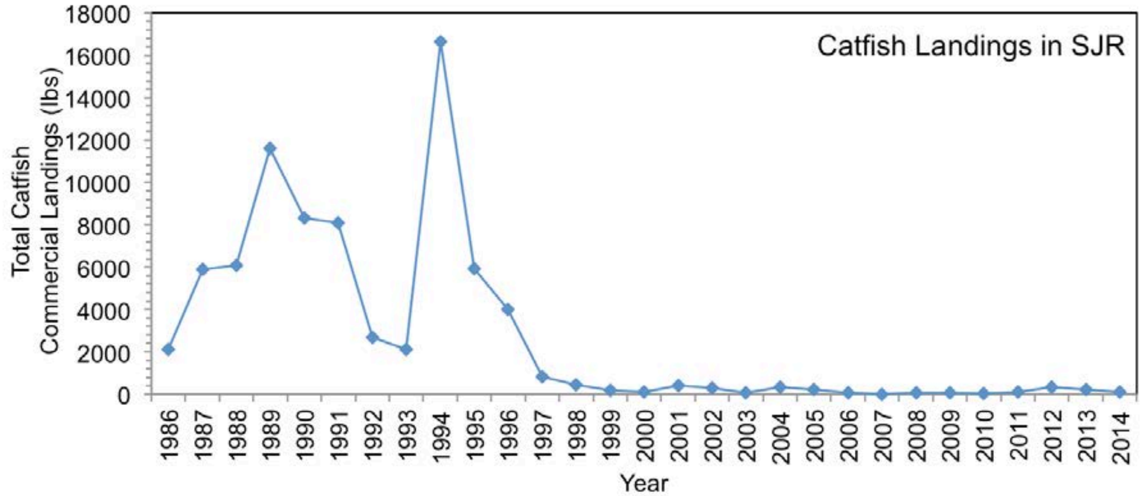


*Figure 3.7. Commercial landings (in lbs.) of catfish within the lower basin of the St. Johns River from 1986 to 2014. Note that the gill net ban went into effect in 1995. (**FWRI 2015b**)*

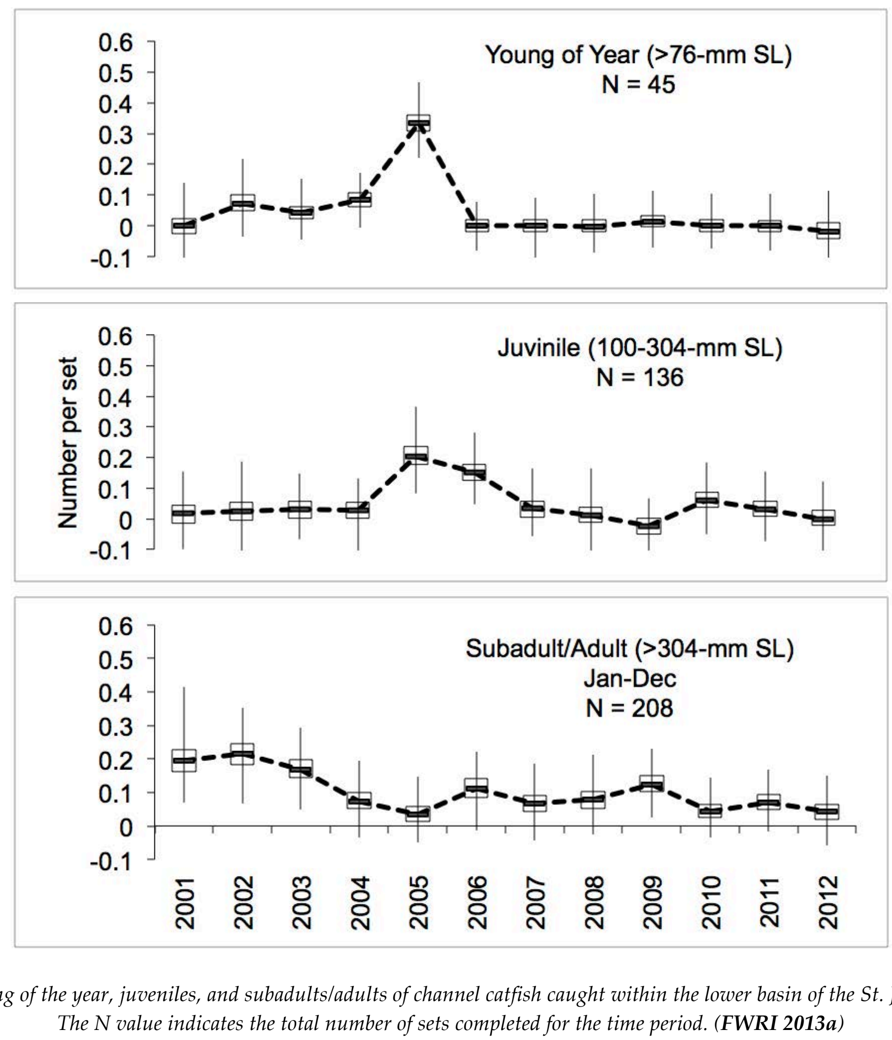


*Figure 3.8. Number of young of the year, juveniles, and subadults/adults of channel catfish caught within the lower basin of the St. Johns River from 2001-2012. The N value indicates the total number of sets completed for the time period. (**FWRI 2013a**)*

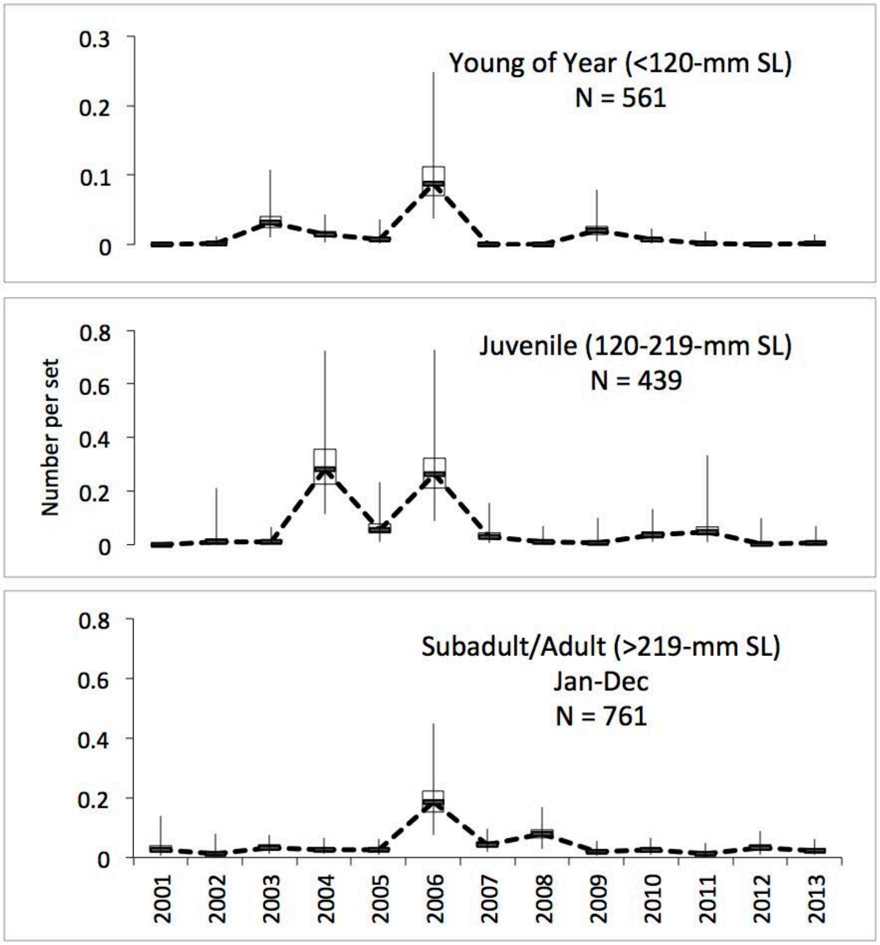


*Figure 3.9. Number of young of the year, juveniles, and subadults/adults of white catfish caught within the lower basin of the St. Johns River from 2001-2013. The N value indicates the total number of sets completed for the time period. (**FWRI 2014a**)*

3.2.6.4. Current Status and Future Outlook

Both species of catfish are generally common in the St. Johns River. The decrease in commercial landings may be more related to changes in fishing regulations over the years, although this is not known for sure. Further, both species of catfish are commonly raised in hatcheries and stocked in lakes and ponds throughout Florida. If future research suggests that their abundance is decreasing to unacceptable levels, areas of the river can be re-stocked. FWC is in the process of implementing freshwater species into its marine trip ticket program to more effectively assess freshwater landings in various parts of Florida. Consequently, the potential exists for overfishing of these species in the future and with the exception of Fish Management Areas, there is a bag limit of 6 fish per person on channel catfish, no bag limit for white catfish (**FWC 2015a**). Taking everything into account, the current STATUS of Freshwater Catfish is *uncertain*, and the TREND is *worsening*.

3.2.7. Striped Mullet (Mugil cephalus)

http://www.floridafishandhunt.com/.../stripemul.jpg

3.2.7.1. General Life History

Striped mullet (also known as black mullet) are detritivores that have a wide salinity range. They are abundant in freshwater and inshore coastal environments often being found near mud bottoms feeding on algae, and decaying plant material. Mullet migrate offshore to spawn with their resultant larvae eventually drifting back to coastal waters and marsh estuaries. Developing individuals will become sexually mature at three years and live from 4-16 years. Older fish may ultimately reach lengths of up to three feet.

3.2.7.2. Significance

Mullet are considered extremely important in benthic food webs in all sections of the LSJR. They are abundant and significant in the transfer of energy from the detrital matter they feed on to their predators such as birds, seatrout, sharks and marine mammals. The commercial mullet fishery has been the largest among all fisheries in the St. Johns for many years with over 100,000 lbs. harvested annually. Additionally, mullet are sought after recreationally for their food and bait value.

3.2.7.3. Trend

Commercial landings have been fairly variable since the 1980s (Figure 3.10). Commercial landings and landings per trip have been consistent in the past with a decline in the past year (Appendix 3.2.7a). The FWRI data set shows variable yearly abundances from 2001 to 2013 (Figure 3.11). Kendall tau correlation analyses revealed no temporal trend in number per set for young of the year (τ =-0.078; N.S.), juveniles (τ =0.154; NS), nor subadults/adults (τ =-0.256; N.S.), Young of the year appear in the river in January and become juveniles within one year (Appendix 3.2.7b).

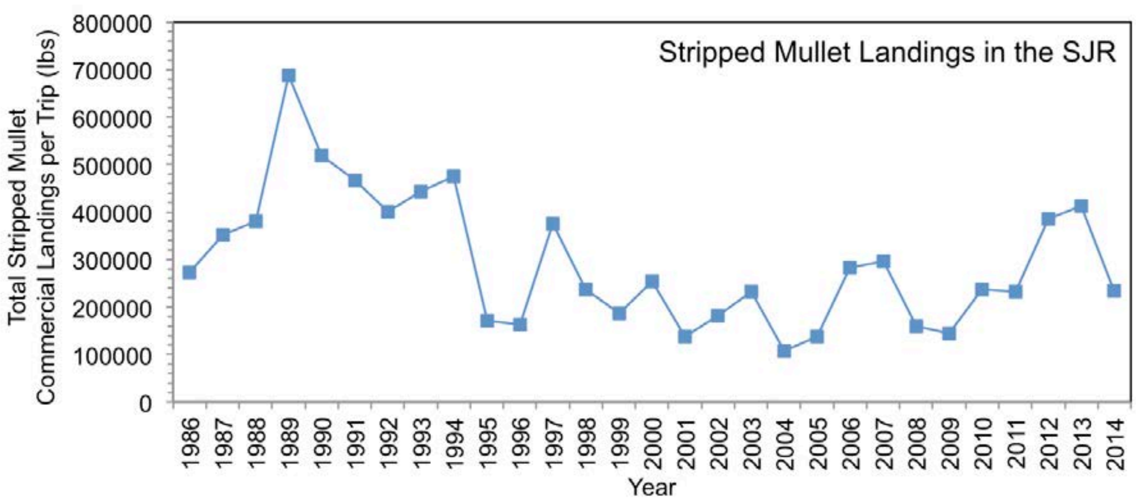


*Figure 3.10. Commercial landings (in lbs.) of striped mullet within the lower basin of the St. Johns River from 1986 to 2014. (**FWRI 2015b**)*

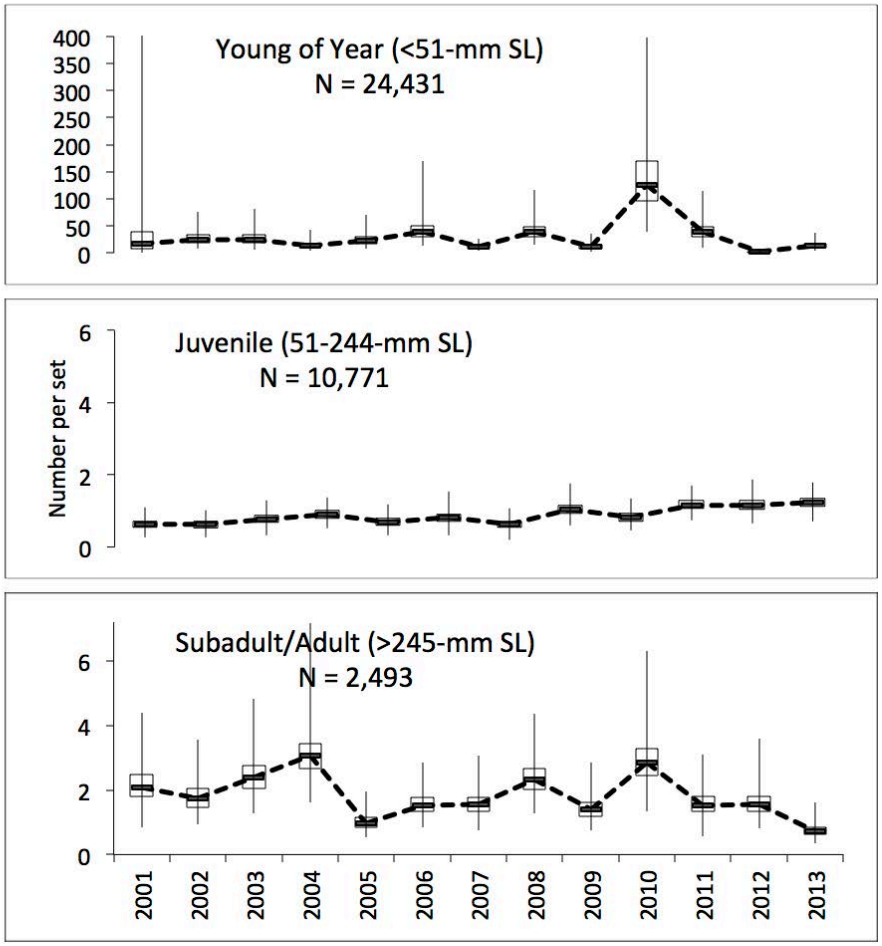


*Figure 3.11. Number of young of the year, juveniles, and subadults/adults of striped mullet caught within the lower basin of the St. Johns River from 2001-2013. The N value indicates the total number of sets completed for the time period. (**FWRI 2014a**)*

3.2.7.4. Current Status & Future Outlook

Striped mullet in the St. Johns River continue to be important commercially and recreationally. Populations appear to be healthy and sustainable into the foreseeable future along the east coast of Florida (**Mahmoudi 2005**). Recreational fishing limitations are 50 fish maximum per person per day (includes Striped and Silver mullet). There is a vessel limit of 50 fish (September 1st-January 31st, and 100 fish from February 1st to August 31st). There is no closed season (**FWC 2015c**). Taking everything into account, the current STATUS of Striped Mullet is *satisfactory*, and the TREND is *uncertain*.

3.2.8. Southern Flounder (Paralichthys lethostigma)

http://www.uvm.edu/~jbartlet/nr260/animal%20life/marine/southernflounder.gif

3.2.8.1. General Life History

The southern flounder is a common flounder in inshore channels and estuaries associated with the St. Johns River. It is a bottom-dwelling predator that feeds on shrimp, crabs, snails, bivalves and small fish. During the fall and winter it moves offshore to spawn. Larvae will develop and drift in the plankton while being transported (primarily via wind driven currents) back to estuaries and lagoons where they will settle and develop into juveniles and then adults. The southern flounder may grow up to 36 inches and live to approximately three years of age.

3.2.8.2. Significance

Flounder are important ecologically, recreationally and commercially to humans in the lower St. Johns River area. They are abundant and important in maintaining ecological balance in their roles as both predator and prey. They feed on small invertebrates such as bivalves and snails, and are preyed on by sharks, marine mammals and birds. The commercial flounder fishery is one of the larger ones in Northeast Florida. Flounder are also highly sought after recreationally for their excellent food value.

3.2.8.3. Trend

Commercially, total landings of all flounders have decreased after 1995 (Figure 3.12; Appendix 3.2.8a). Total flounder landings have decreased significantly for the north river section and increase in the southern section of the river (Appendix 3.2.8a). However, the commercial catch per trip increased in the northern section of the river and a decrease in the southern section of the river. The mid-1990s decrease in commercial landings may be due to the impact of the gill net ban. Finally, the FWRI data set shows no upward or downward trends in abundance from 2001 to 2013 (Figure 3.13). Kendall tau correlation analyses revealed no temporal trend in number per set for young of the year (τ =0.051; N.S.), juvenile (τ = 0.103; N.S.) nor subadults/adults (τ =-0.103; N.S.). Young of the year appear in the river in January and become juveniles within approximately one year (Appendix 3.2.8b).

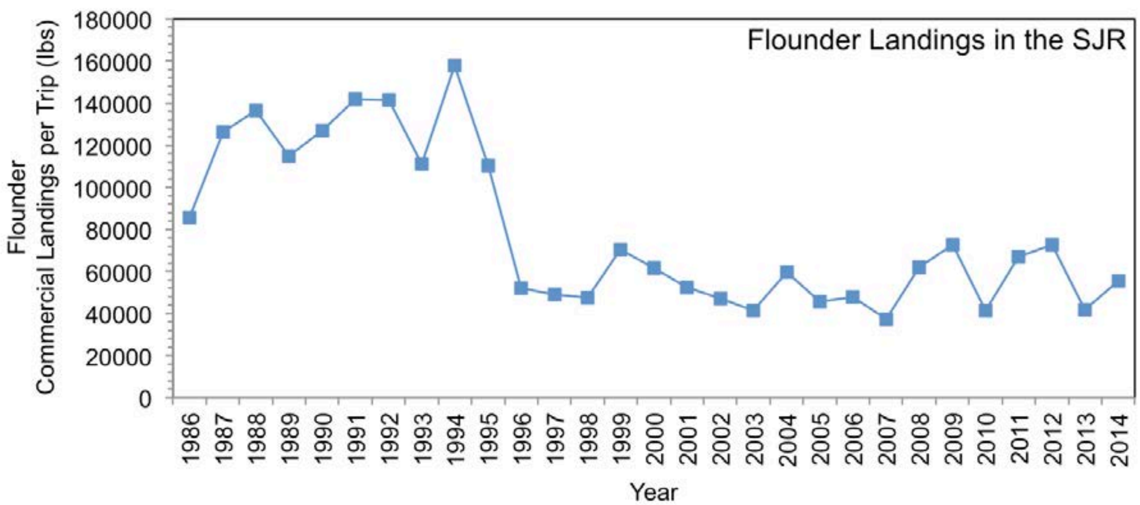


*Figure 3.12. Commercial landings (in lbs.) of southern flounder within the Lower Basin of the St. Johns River from 1986-2014. (**FWRI 2015b**)*

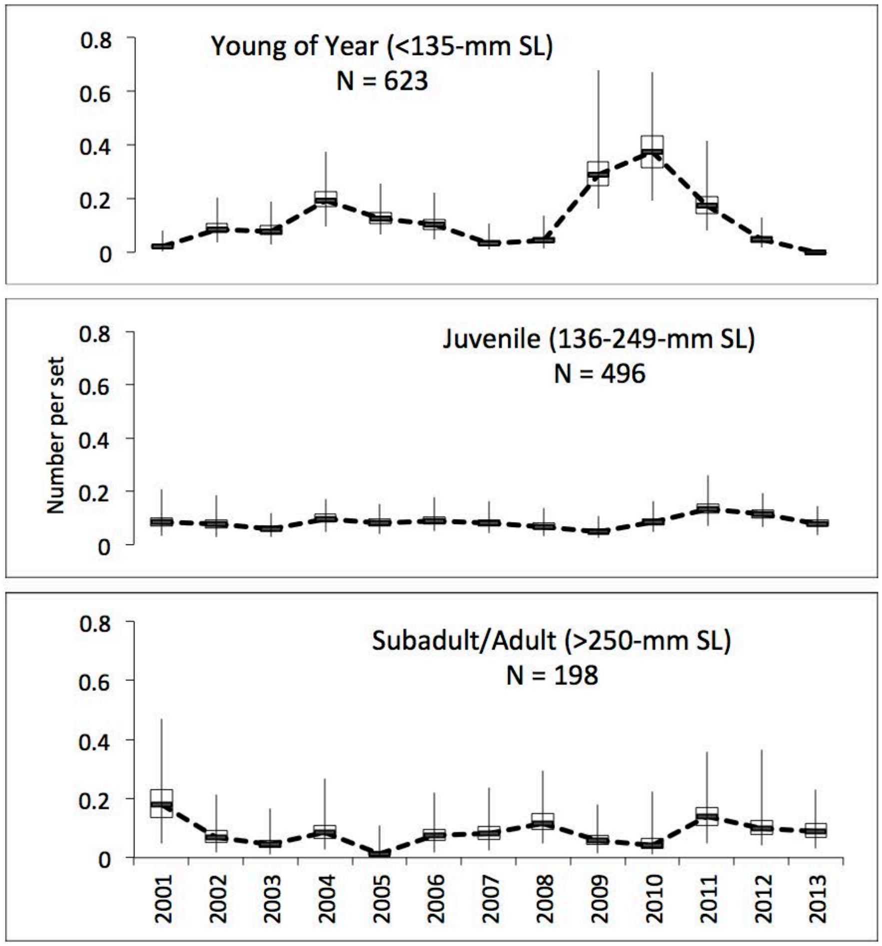


*Figure 3.13. Number of young of the year, juveniles, and subadults/adults of southern flounder caught within the lower basin of the St. Johns River from 2001-2013. The N value indicates the total number of sets completed for the time period. (**FWRI 2014a**)*

3.2.8.4. Current Status & Future Outlook

The southern flounder continues to be important recreationally and commercially in the LSJR. They are fairly common in the St. Johns River, and appear to have no short-term risk of being overfished along the Florida east coast (**FWRI 2008c**). However, to help ensure their maintenance, it is important to have a better understanding of the reproductive and life history ecology of populations within the river. Recreationally, flounder can be caught all months of the year. Legal minimum size limit is 12 inches, with a daily limit of ten fish per person (**FWC 2015c**). Taking everything into account, the current STATUS of Southern Flounder is *uncertain*, and the TREND is *uncertain*.

3.2.9. Sheepshead (Archosargus probatocephalus)

http://myfwc.com/marine/fish/sheepshead.jpg

3.2.9.1. General Life History

Sheepshead are common nearshore and estuarine fish that are very often associated with pilings, docks and jetties. They have an impressive and strong set of incisor teeth that are used to break apart prey such as bivalves, crabs and barnacles. Adults will migrate offshore during the spring to spawn. Fertilized eggs will develop into larvae offshore and be carried towards the coast by currents primarily driven by the wind. The larvae will enter the mouths of inlets and settle in shallow grassy areas. Developing individuals may reach a maximum length of three feet.

3.2.9.2. Significance

Sheepshead are ecologically, recreationally and commercially important in northeast Florida. They are important in maintaining the estuarine and coastal food web as both a predator and prey. They feed on bottom dwelling invertebrates (i.e. bivalves and barnacles) and are fed on by larger predators such as sharks and marine mammals. The commercial fishery is one of the larger ones within the river. Recreationally, sheepshead are valued by fisherman in the area for their high food value.

3.2.9.3. Trend

Commercial landings seemed stable from 1997 to 2003, then declined until 2008. Since 2008 the trend has been increasing, but remains below 2003 levels (Figure 3.14). Total landings over time showed a declining trend, as did landings per trip in both north and south sections of the river (Appendix 3.2.9a). It should be noted that data from the southern counties most likely includes a significant number of fish caught in the ICW. The FWRI data set shows no upward or downward trends in abundance from 2001 to 2013 (Figure 3.15). Kendall tau correlation analyses revealed no temporal trend in number per set for young of the year (τ =-0.051; N.S.), juvenile (τ =-0.308; N.S.) nor subadults/adults (τ =-0.154; N.S.). There are more subadults/adults encountered than the other two age classes (Figure 3.15). Young of the year appear in the river in May and become juveniles within approximately one year (Appendix 3.2.9b).

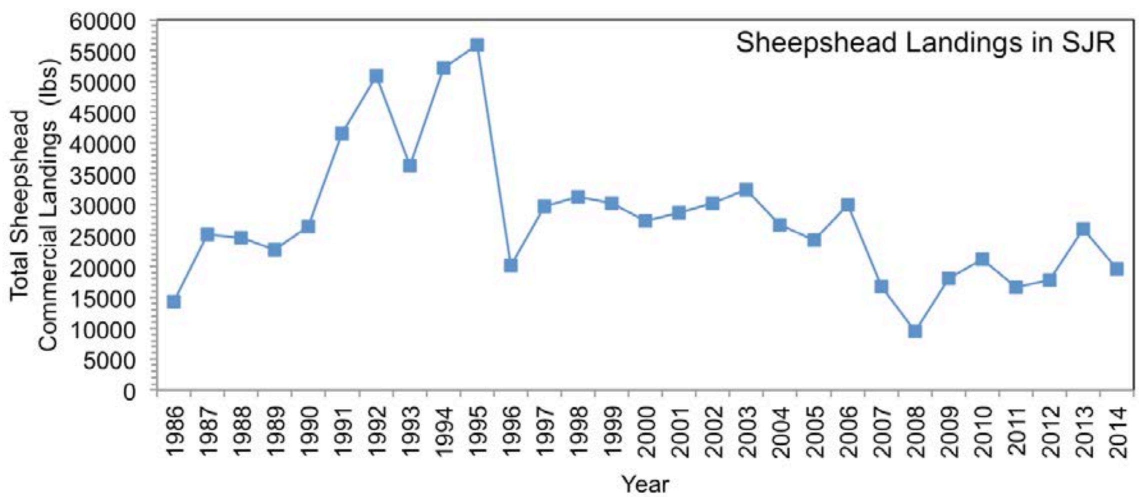


*Figure 3.14. Commercial landings (in lbs.) of sheepshead within the lower basin of the St. Johns River from 1986 to 2014. (**FWRI 2015b**)*

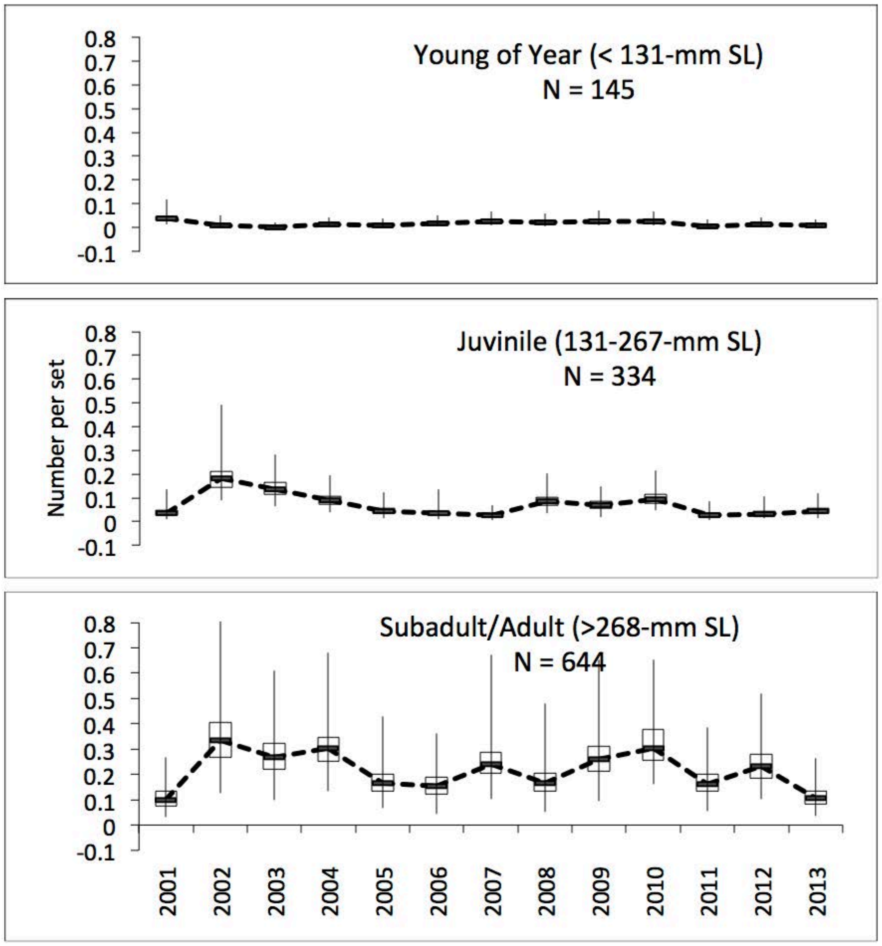


*Figure 3.15. Number of young of the year, juveniles, and subadults/adults of sheepshead caught within the lower basin of the St. Johns River from 2001-2013. The N value indicates the total number of sets completed for the time period. (**FWRI 2014a**)*

3.2.9.4. Current Status & Future Outlook

Sheepshead continue to be important as both recreational fishermen and commercial fisheries. They are common in the St. Johns River, and appear abundant enough along the Florida east coast to maintain populations with current levels of harvest (**Munyandorero, et al. 2006**). They can be caught all months of the year. Legal minimum size limit is 12 inches with a daily limit of fifteen fish per person (**FWC 2015c**). Taking everything into account, the current STATUS of Sheepshead is *satisfactory*, and the TREND is *unchanged*.

3.2.10. Atlantic Croaker (Micropogonias undulatus)

http://www.floridafishandhunt.com/.../atlcroaker.jpg

3.2.10.1. General Life History

The Atlantic croaker is a bottom-dwelling predator that is commonly encountered around rocks and pilings in estuarine habitats. They are named for the croaking sound they make which is accomplished by scraping muscles against their swim bladder. They use their barbels to sense prey such as large invertebrates and fish. Adults will migrate offshore during winter and spring to spawn. Their offspring will develop in the plankton and be transported back inshore, where they will settle in vegetated shallow marsh areas. They grow rapidly and may attain a maximum length of 20 inches.

3.2.10.2. Significance

Croakers are important to the LSJR in a number of ways. They are very abundant and consequently extremely important in the food web as both predator and particularly as prey. They feed on small invertebrates, and are fed on by red drum, seatrout, and sharks. For many years, their commercial fishery has been one of the biggest in the LSJR. Additionally, they are recreationally caught for their food value.

3.2.10.3. Trends

Commercially, total landings have decreased for the northern section of the river but have been temporally consistent to the south (Figure 3.17: Appendix 3.2.10a). The catch per trip was not significantly different temporally for both the north and south sections of the river. In both sets of commercial data, landings are lower in the southern sections of the river (Appendix 3.2.10a). The FWRI data set shows consistent trends in abundance from 2001 to 2013 (Figure 3.17). Kendall tau correlation analyses revealed no temporal trend in number per set for young of the year (τ =0.051; N.S.), juvenile (τ =0.103; N.S.), nor subadults/adults (τ =0.256; NS). Young of the year appear in the river in October and become juveniles in approximately one year (Appendix 3.2.10b). Generally, smaller Atlantic Croaker have been observed in more freshwater areas of the river, and appear to move to more estuarine areas as they get larger (**Brodie 2009**).

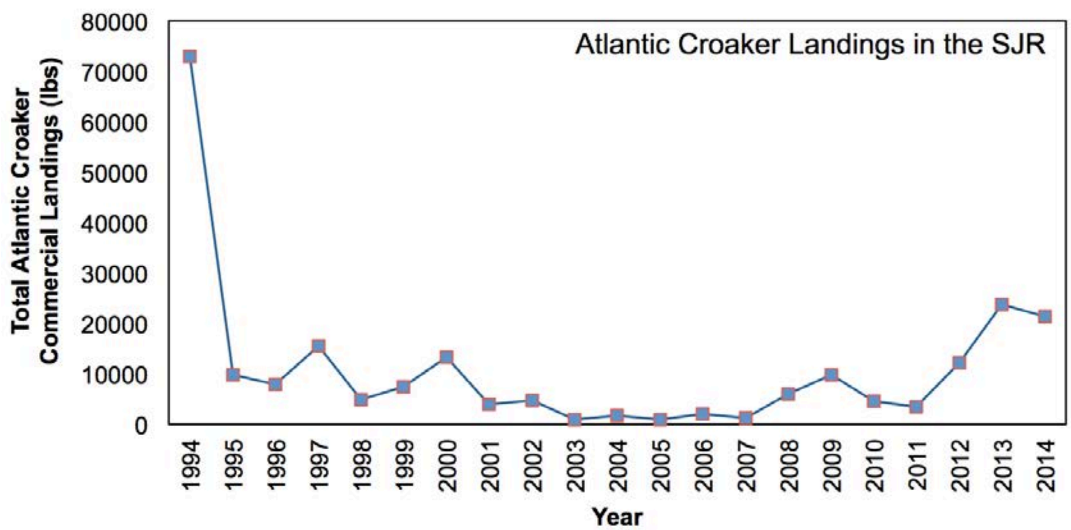


*Figure 3.16. Commercial landings (in lbs.) of Atlantic croaker within the lower basin of the St. Johns River from 1986 to 2014. (**FWRI 2015b**)*

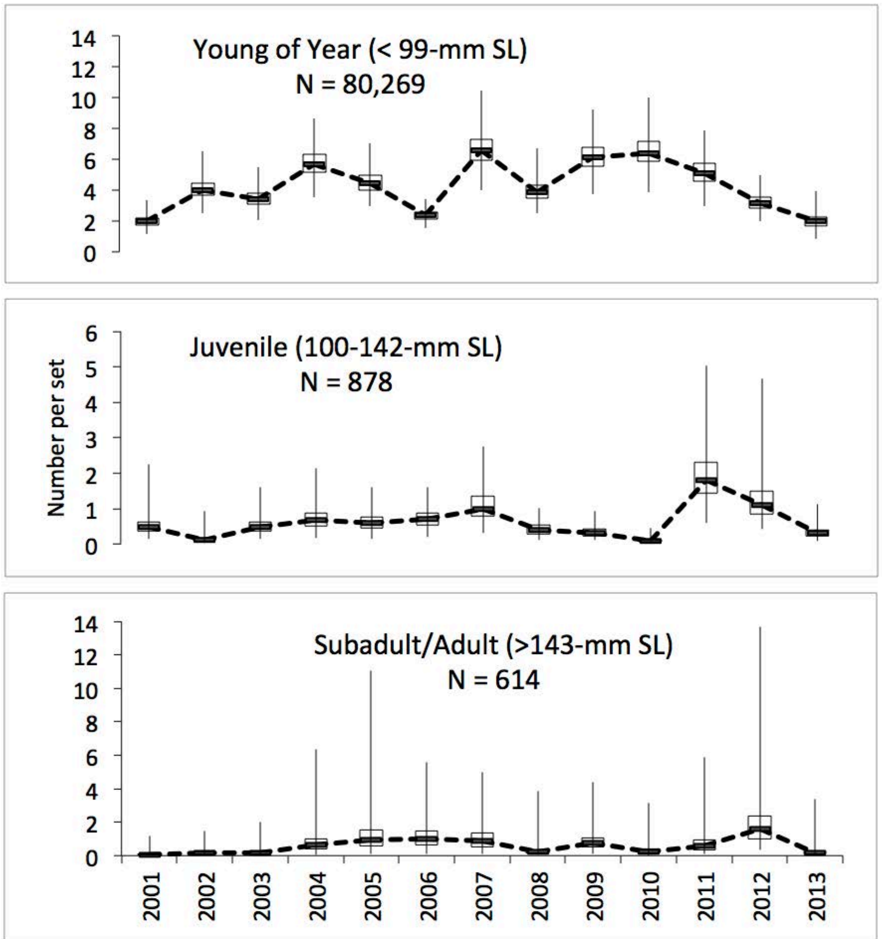


*Figure 3.17. Number of young of the year, juveniles, and subadults/adults of Atlantic croaker caught within the lower basin of the St. Johns River from 2001-2013. The N value indicates the total number of sets completed for the time period. (**FWRI 2014a**)*

3.2.10.4. Current Status & Future Outlook

Atlantic croaker are common in the LSJR and continue to be important commercially and recreationally. While there does not appear to be a major risk of landings decreasing significantly in the next few years, there has never been a stock assessment performed on any Florida population (**FWRI 2008b**). Recreationally, they can be caught all months of the year, and there is currently no legal size limit (**FWC 2015c**). Taking everything into account, the current STATUS of Atlantic Croaker is *satisfactory*, and the TREND is *unchanged*.

3.2.11. Baitfish

http://floridasportfishing.com/magazine/baifish

3.2.11.1. General Life History

Baitfish encompass the multitude of small schooling fish that are the most abundant fishes in the lower St. Johns River. There are at least two-dozen species of baitfish in Florida including anchovies, menhaden, herring, killifish, sheepshead minnows and sardines. Many of the baitfish species such as Spanish sardines and thread herring are planktivores. However, many may also eat small animals such as crabs, worms, shrimp and fish.

There is high diversity in life history patterns among baitfish species in the LSJR. However, most migrate seasonally either along the coast and/or away from shore. Many become sexually mature at about one year reproducing by spawning externally at either the mouth of estuaries (menhaden) or offshore (sardines, anchovy). In both cases, larvae hatch out, and are carried by currents to estuaries where the young will eventually join large schools of juvenile and adult fish. In most cases, individuals do not live longer than four years.

3.2.11.2. Significance

Baitfish are very important to the LSJRB because they are extremely important in the food web as prey for a number of larger fish species. They are also important as omnivores that recycle plant and/or animal material that is then available for higher trophic levels. Bait fish are commercially and recreationally utilized for their bait value. Recreational use includes bait for fishing, whereas commercial uses may include products such as fertilizers, fishmeal, oil and pet food. The primary fisheries in this group are focused on anchovy, menhaden, sardines, and herring (**FWC 2000**). However, smaller fisheries catch killifish, sheepshead minnows and sardines.

3.2.11.3. Trends

Commercial landings decreased in the mid-1990s and have been sporadic since (Figure 3.18; Appendix 3.2.11). The decrease during the mid-1990s may have been due to the Florida gill net ban. While landings of baitfish have remained temporally consistent, the catch per trip has decreased for the northern section of the river. Further, baitfish landings seem to be higher in the southern sections of the river.

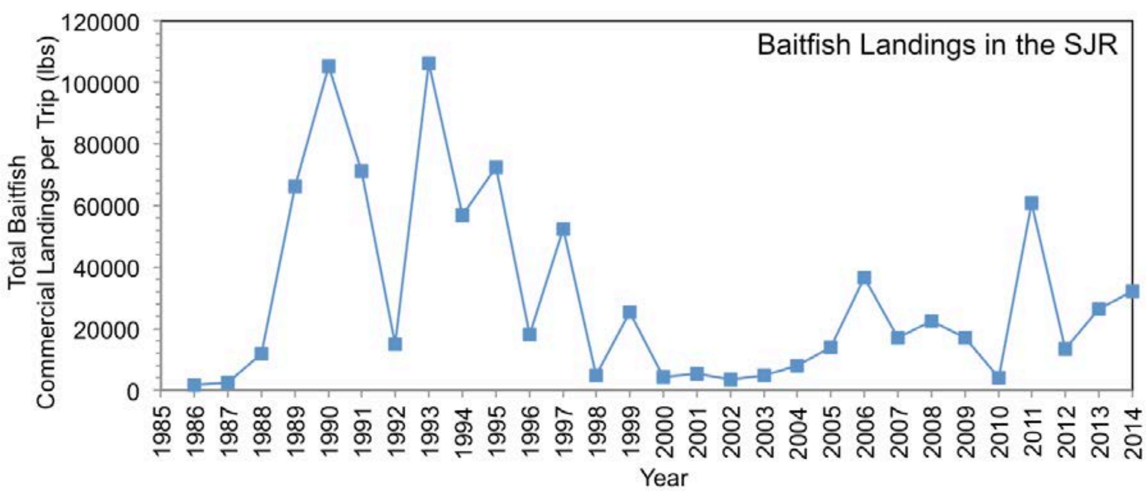


*Figure 3.18. Commercial landings (in lbs.) of baitfish within the lower basin of the St. Johns River from 1986 to 2014 (**FWRI 2015b**)*

3.2.11.4. Current Status & Future Outlook

Baitfish are very abundant in the LSJR and continue to be important commercially and recreationally. They are likely to be sustainable into the foreseeable future. However, researchers at the Fish and Wildlife Research Institute (FWRI) currently are monitoring and assessing the effects of their fisheries management efforts. Recreationally, they can be caught all months of the year. There is no legal size limit (**FWC 2015c**). Taking everything into account, the current STATUS of Baitfish is *satisfactory*, and the TREND is *unchanged*.

3.3. Invertebrate Fishery

3.3.1. General description

The invertebrate community is very important to the overall ecology of the LSJRB. It is also important economically for commercial and recreational fisheries. Commercially harvested invertebrates in the lower basin include blue crabs, bait shrimp and stone crabs. Of the five counties studied (2005-2014), Duval County generally reported the highest catch of crabs (mean 577,594 lbs. per year; sd ± 188, 180 lbs. per year). Recreational fisheries in the area are probably significant for the species mentioned although the level of significance is unclear since there are few reports on recreational landings.

3.3.2. Blue Crab (Callinectes sapidus)

http://www.jacqueauger.com/.../natural/blue_crab.jpg

3.3.2.1. General Life History

The blue crab (**FWRI 2013b**) is a very common benthic predator that inhabits estuarine and nearshore coastal habitats in Northeast Florida. They are general feeders (omnivores) that will eat fish, aquatic vegetation, molluscs, crustaceans and worms (**FWRI 2002**). In the St. Johns River, they reproduce from March to July, and then again from October to December (**Tagatz 1965**; **Tagatz 1968b**; **Tagatz 1968a**). Females carry fertilized eggs and migrate towards the more marine waters near the mouth of the river where they will release their eggs into the water. At this point, the young are called zoea, and they drift and develop along the continental shelf for 30-45 days. Wind and currents eventually transport the larger megalops larvae back to the estuarine parts of the river where they will settle in submerged aquatic vegetation (SAV) that serves as a nursery for them. Within 6-20 days of landing at this location, the young will molt and become what is recognizable as a blue crab. In 12-18 months, young crabs will then become sexually mature, ultimately reaching a width of eight inches.

3.3.2.2. Significance

Blue crabs are very important in both the benthic and planktonic food webs in the St. Johns River. They are important predators that can affect the abundance of many macroinvertebrates such as bivalves, smaller crabs, and worms. They are also important prey for many species. Smaller crabs provide food for drum, spot, croaker, seatrout and catfish, while sharks and rays eat larger individuals.

A strong recreational blue crab fishery exists, although there are relatively few data on it. The blue crab fishery is the largest commercial fishery in the LSJRB (Figure 3.1). In 2013, it accounted for over 73% of commercial fisheries in the river with 1,615,232 pounds harvested. St. Johns County reported the highest number of crab landings (496, 362 lbs.), followed by Duval (482, 063 lbs.), Putnam (457, 854 lbs.), Clay (162, 322 lbs.), and Flagler County (16, 631 lbs.)

3.3.2.3. Data Sources

Blue crab data were collected from commercial reports (1994 to 2014) of landings made to the state, and research (2001-2013) from the FWRI.

3.3.2.4. Limitations

The primary limitation with the commercial landing data is that it does not account for young crabs that are too small to be harvested. Additionally, there may be uncertainties regarding location of where the crabs are collected. For instance, fisherman (crabbers) landings reports are made from their home counties, although it is uncertain what part of the river the crabs were actually caught. Changes in harvesting regulations through the years limit what can be said of landings between certain time periods. In this report, total landings are graphed. However, in order to best assess comparison of landings over the years, landings per trip are calculated, and trends investigated using Kendall tau analysis. In terms of the FWRI collection methods assessed in this study, the subsequent data are likely to not have caught the complete size range of crabs that exist within the river.

3.3.2.5. Trend

Commercial landings of blue crabs have been variable, but trending downward for north and south sections of LSJR from 1986 to 2014. However, from 2011 to 2012 landings increased more than over the past decade, but fell sharply in 2013

(Figure 3.19). Additionally, more landings occur in the southern versus northern section of the river (Appendix 3.3.2a). There was a significant decrease in the amount of blue crabs landed per trip over time for the north section of the river (1986-2013). The FWRI data set shows consistent trends in abundance from 2001 to 2013 (Figure 3.20). Kendall tau correlation analyses revealed no temporal trend in number per set for juvenile (τ =-0.051; N.S.), or adult crabs (τ =0.128; N.S.). The appearance of juveniles (20-126 mm "shell" or carapace width) appears to occur in highest numbers beginning in August (Appendix 3.3.2b).

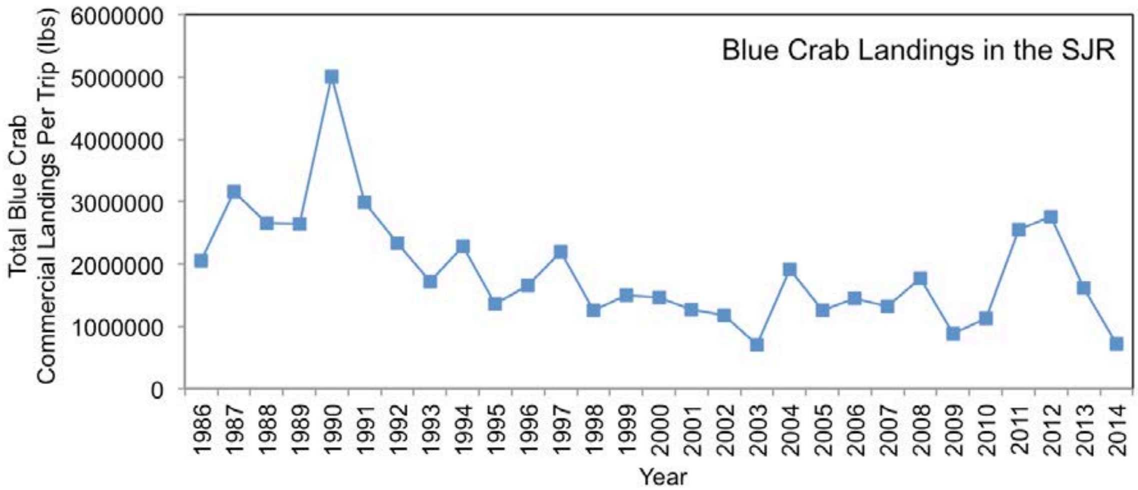


*Figure 3.19. Commercial landings (in lbs.) of blue crabs within the lower basin of the St. Johns River from 1986 to 2014. (**FWRI 2015b**)*

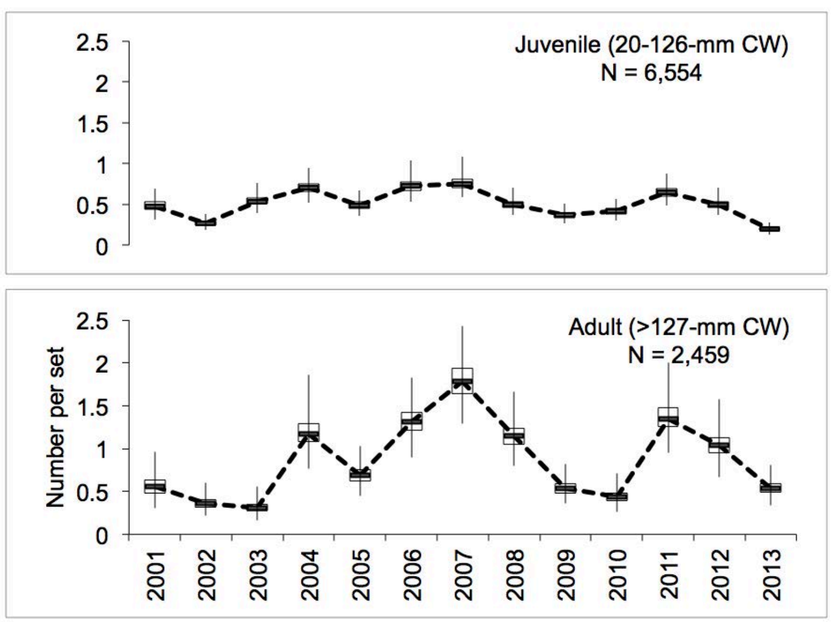


*Figure 3.20. Number of juveniles and adults of blue crabs caught within the lower basin of the St. Johns River from 2001-2013. The N value indicates the total number of sets completed for the time period. (**FWRI 2014a**)*

3.3.2.6. Current Status & Future Outlook

The blue crab commercial fishery continues to be the premier invertebrate fishery within the LSJRB. The recreational fishery is also likely to be very large, although there is no information available on it.

While common within the river, there is uncertainty regarding whether blue crabs are being overfished or not in Florida. This uncertainty is because the maximum age of blue crabs in Florida is not known. Maximum age is one component that is used in a stock assessment model. Depending on the value used, it can affect whether the model suggests crabs are overharvested or not (**Murphy, et al. 2007**). Consequently, this piece of information is needed to more accurately assess blue crab stocks in Florida. Currently, there is no required license to fish recreationally using five or fewer traps. In the St.

Johns River, five or fewer traps can be used to recreationally catch blue crabs throughout the year (ten gallons whole per harvester per day) except from January 16th to 25th. Crabs can also be caught using dip nets, crab pots, and hand-lines (**FWC 2015c**). Taking everything into account, the current STATUS of Blue Crab is *uncertain*, and the TREND is *uncertain*.

3.3.3. Penaeid shrimp - White, pink & brown (Litopenaeus setiferus, Farfantepenaeus duorarum & F. aztecus)

3.3.3.1. General Life History

There are three penaeid shrimp species that exist within the estuaries and nearshore waters of the northeast Florida region. They are the white, pink, and brown shrimp. The white shrimp is the most common species in local waters. All three are omnivorous feeding on worms, amphipods, molluscs, copepods, isopods and organic detritus. White shrimp reproduce during April to October, whereas pink and brown shrimp can spawn year round (**FWRI 2007**). However, peak spawning for brown shrimp is from February to March and from spring through fall for pink shrimp. All species spawn offshore in deeper waters with larvae developing in the plankton and eventually settling in salt marsh tidal creeks within estuaries. From there, young will develop for approximately 2-3 months. As they get larger, they start to migrate towards the more marine waters of the ocean where they will become sexually mature when they reach lengths between 3-5 inches. While they generally do not live long (a maximum 1.5 years), they may reach maximum lengths of up to seven inches.

3.3.3.2. Significance

Penaeid shrimp are very important in both the benthic and planktonic food webs in the St. Johns. They are important predators that can affect the abundance of many small macroinvertebrates (see list above). They are also important prey for many species. As smaller individuals such as post-larvae and juveniles, they provide food for sheepshead minnows, insect larvae, killifish and blue crabs. As adult shrimp, they are preyed on by a number of the finfish found within the river.

The LSJR supports both recreational and commercial shrimp fisheries. The recreational fishery is likely to be large although there is relatively little information on it. In contrast, the commercial shrimp fishery is one of the largest fisheries in the region. However, most shrimp obtained for human consumption are caught by trawlers offshore. Commercial trawling in the LSJR represents a much smaller fishery.

3.3.3.3. Data Sources

Penaeid shrimp data were collected from commercial reports made to the State (1986 to 2014). These comprised of total bait shrimp landings that were generally collected within the river. These data likely include white, brown and pink shrimp, although their relative proportions are unknown. Data for only white shrimp were also collected and assessed from research (2001-2012) from the FWRI.

3.3.3.4. Limitations

The primary limitation with the commercial landing data is there are uncertainties regarding the location of where shrimp are collected. For instance, shrimp fisherman landings reports are made from their home counties although it is sometimes uncertain what part of the river shrimp were actually caught in. Additionally, changes in harvesting regulations through the years may limit what can be said of landings between certain time periods. In this report, total landings are graphed. However, in order to best assess comparison of landings over the years, landings per trip are calculated, and trends investigated using Kendall tau analysis. In terms of the FWRI data set, the collection methods assessed in this study may not have caught the complete size range of shrimp that exist within the river.

3.3.3.5. Trend

The commercial total landings of bait shrimp (1986-2014) have been variable with a downward trend in the southern section of the river (Figure 3.21). However, from 2001 to 2012 there have been drastic fluctuations among the years with peak landings occurring in 2004. Less fluctuation has occurred in recent years with far more bait shrimp are reported in the northern versus southern sections of the LSJR (Appendix 3.3.3a). The FWRI data set shows consistent trends in abundance for white shrimp from 2001 to 2013 (Figure 3.22). Kendall tau correlation analyses revealed an increasing trend in the number of white shrimp captured per set (τ =0.487; p=0.01; n=13). The highest numbers of small white shrimp were encountered in the river from May to July (Appendix 3.3.3b).

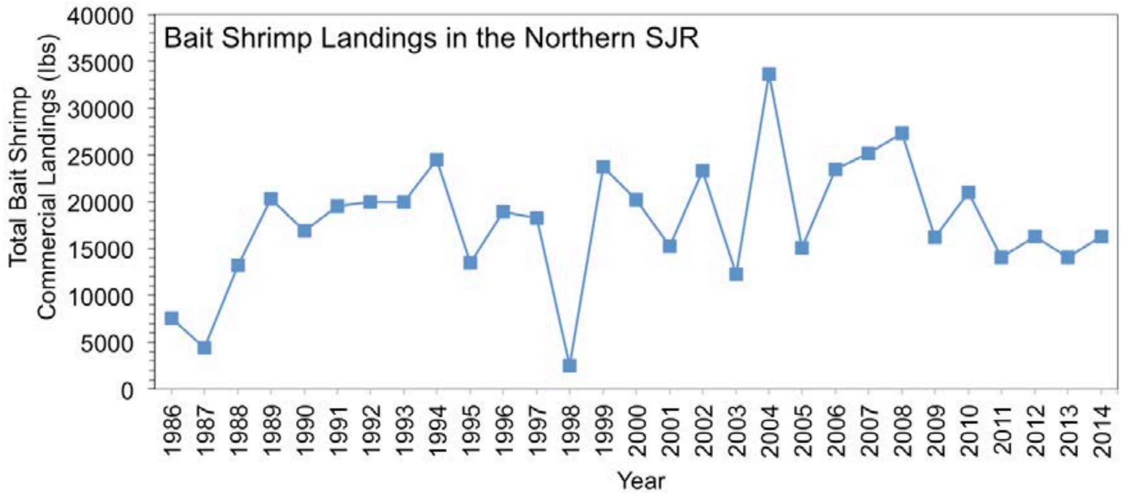


*Figure 3.21. Commercial landings (in lbs.) of bait shrimp within the lower basin of the St. Johns River from 1986 to 2014. (**FWRI 2015b**)*

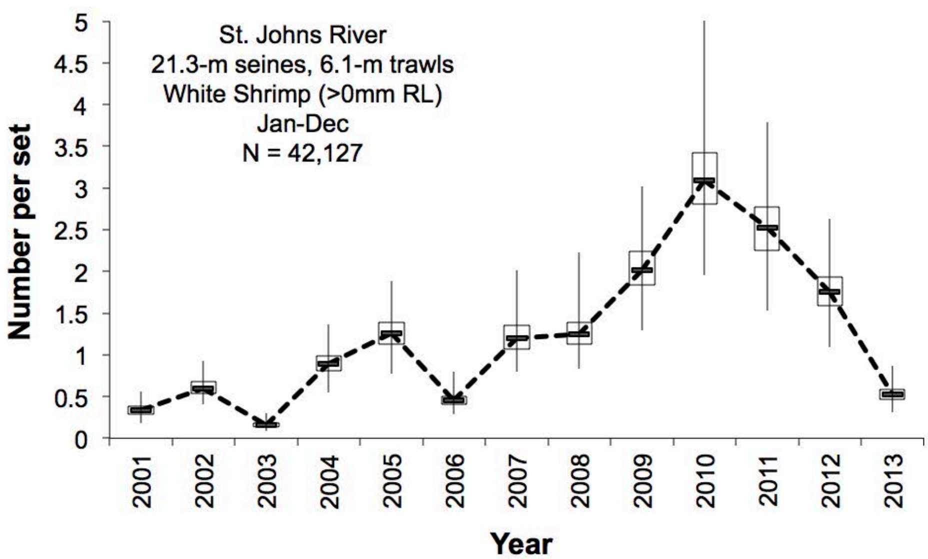


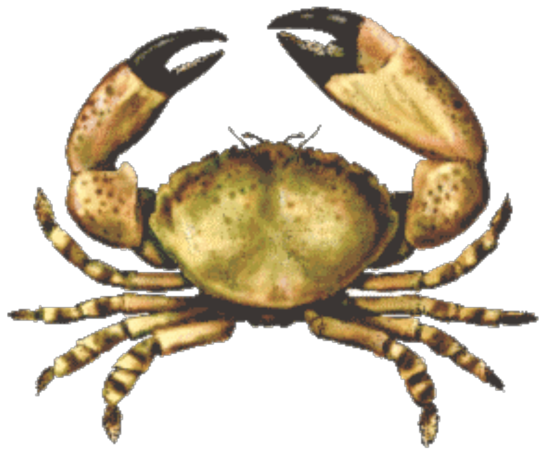
*Figure 3.22. Number of juveniles and adults of white shrimp caught within the lower basin of the St. Johns River from 2001-2013. The N value indicates the total number of sets completed for the time period. (**FWRI 2013a**)*

3.3.3.6. Current Status & Future Outlook

Commercial harvesting of penaeid shrimp for bait is a relatively small fishery in the LSJR. The recreational fishery is probably moderately sized, although there are no available data on it. Generally, penaeid shrimp are very abundant in the region. They may be at slight risk of being overfished in the south Atlantic region (see **FWRI 2008a** for a review). However, the South Atlantic Fishery Management Council and Gulf of Mexico Fishery Management Council have established fishery management plans for shrimp to try to ensure they are not overharvested (**FWRI 2008a**). Taking everything into account, the current STATUS of Shrimp is *uncertain*, and the TREND is *uncertain*.

Recreationally, shrimp can be harvested (five gallons per person per day) via dip net, cast net, and push net, one frame net or beach seine. The season is closed during April and May in Nassau, Duval, St. Johns, Putnam, Flagler and Clay Counties (**FWC 2015c**).

3.3.4. Stone Crabs (Menippe mercenaria)



http://www.ocean.udel.edu/.../species_stonecr.gif

3.3.4.1. General Life History

The stone crab is a fairly common benthic predator that inhabits hard bottoms (such as oyster reefs) and grass beds in the northeast Florida area. Stone crabs are opportunistic carnivores feeding on oysters, barnacles, snails, clams, etc. In Florida, stone crabs reproduce from April through September (**FWRI 2007**). It is unclear where stone crabs sexually reproduce, and females will carry eggs for approximately two weeks before the eggs hatch. The larvae will drift in the plankton and settle and metamorphose into juvenile forms of the adult in about four weeks. In approximately two years, the crabs will then become sexually mature and reach a width of 2.5 inches. They may live as long as seven years.

3.3.4.2. Significance

Stone crabs are important predators and prey in the estuarine community in the St. Johns River. As important predators, they can affect the abundance of many macroinvertebrates such as bivalves, smaller crabs, and worms. They are also important prey when both young and older. As larvae in the plankton they are preyed on by filter-feeding fish, larval fish and other zooplankton. As adults, they are preyed on by many larger predators in the river.

The stone crab fishery is unique in that the crab is not killed. The claws are removed (it is recommended to only take one claw so the animal has a better chance of survival) and the animal is returned to its habitat. While there probably is a recreational stone crab fishery in the area, there is relatively little information on it. The stone crab commercial fishery is relatively new and small in the LSJR. The highest number of claw landings within the river basin likely comes from Duval County. Claw landings from other counties of the LSJR most likely come from collections made in the ICW.

3.3.4.3. Data Sources

Stone crab data were collected from commercial reports of landings made to the State between 1986 and 2014. There were no available recreational landings data.

3.3.4.4. Limitations

The primary limitation with the commercial landing data is it does not account for young crabs that are too small to be harvested. Additionally, there are uncertainties regarding location of where crab claws are collected. For instance, fisherman (crabbers) landings reports are made from their home counties although the crab claws may have been collected elsewhere. For stone crabs reported by southern counties of the lower basin, it is more likely that the claws were collected in the Intracoastal Waterway (ICW) than the river itself. Additionally, changes in harvesting regulations through the years may limit what can be said of landings between certain time periods. Total landings are shown in this report. However, in order to best assess comparison of landings over the years, landings per trip are calculated, and trends investigated using Kendall tau analysis.

3.3.4.5. Trend

Commercial landings of stone crabs have been variable despite an increase in the number of deployed traps (**FWRI 2002**). Peak landings occurred in 1994 and 1997 with generally low landings occurring from 1998 to 2006 (Figure 3.23). Most landings were reported by the more southern counties of the LSJRB (Appendix 3.3.4a). However, this is most likely a reflection of crab claws caught in the Intracoastal Waterway of the more southern counties than in the river itself.

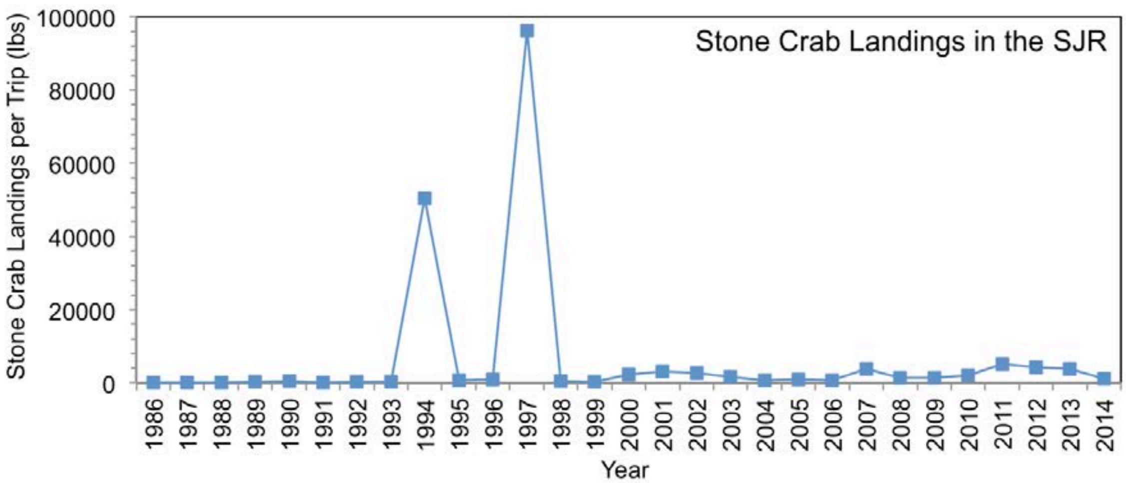


*Figure 3.23. Commercial landings (in lbs.) of stone crab claws within the lower basin of the St. Johns River from 1986 to 2013. (**FWRI 2015b**)*

3.3.4.6. Current Status & Future Outlook

Stone crabs are not currently at risk of being overfished but are probably now at a level of landings that is all that can be harvested under current conditions along the Florida east coast (**Muller, et al. 2006**). To minimize negative impacts from commercial fisherman, the Florida legislature implemented a crab trap reduction program in 2002. Currently, there is a daily limit of one gallon per person, or two gallons per vessel, of minimum-sized 2 ¾-inch claws to only be collected during the season from October 15 to May 15 (**FWC 2015c**). Taking everything into account, the current STATUS of Stone Crab is *satisfactory*, and the TREND is *unchanged*.

4. Aquatic Life

4.1. Submerged Aquatic Vegetation (SAV)

4.1.1. Description

Dating back to 1773, records indicate that extensive SAV beds existed in the river (**Bartram 1928**). Since that time, people have altered the natural system by dredging, constructing seawalls, contributing chemical contamination, and sediment and nutrient loading (**DeMort 1990**; **Dobberfuhl 2007**). SAV found in the LSJRB (see Table 4.1) are primarily freshwater and brackish water species. Commonly found species include: tape grass *(Vallisneria americana)*, water naiad *(Najas guadalupensis)*, and widgeon grass *(Ruppia maritima).* Tape grass forms extensive beds when conditions are favorable. Water naiad and widgeon grass form bands within the shallow section of the SAV bed. Tape grass is a freshwater species that tolerates brackish conditions, water naiad is exclusively freshwater and wigeon grass is a brackish water species that can live in very salty water (**Sagan 2010; White, et al. 2002)**. *Ruppi*a does not form extensive beds. It is restricted to the shallow, near shore section of the bed and has never formed meadows as extensive as *Vallisneria* even when salinity has eliminated *Vallisneria* and any competition, or other factors change sufficiently to support *Ruppia* (**Sagan 2010**).

Other freshwater species include: muskgrass *(Chara sp.)*, spikerush *(Eleocharis sp.)*, water thyme *(Hydrilla verticillata*; an invasive non-native weed), baby's-tears *(Micranthemum sp.)*, sago pondweed *(Potamogeton pectinatus)*, small pondweed *(Potamogeton pusillus)*, awl-leaf arrowhead *(Sagittaria subulata)* and horned pondweed *(Zannichellia palustris)* (**IFAS 2007**; **Sagan 2006**; **USDA 2013**). **DeMort 1990** surveyed four locations for submerged macrophytes in the LSJR and indicated that greater consistency in species distributions occurred south of Hallows Cove (St. Johns County) with tape grass being the dominant species. North of this location widgeon grass and sago pondweed were the dominant species, until 1982-1987 when tape grass coverage increased 30%, and is now the most dominant species encountered.

The greatest distribution of SAV in Duval County is in waters south of the Fuller Warren Bridge (**Kinnaird 1983b**; **Dobberfuhl 2002**; **Dobberfuhl and Trahan 2003**; **Sagan 2004**; **Sagan 2006**; **Sagan 2007**). Submerged aquatic vegetation in the tannin-rich, black water LSJR is found exclusively in four feet or less of water depth. Poor sunlight penetration prevents the growth of SAV in deeper waters. **Dobberfuhl 2007** confirmed that the deeper outer edge of the grass beds occurs at about three feet in the LSJRB. Rapid regeneration of grass beds occurs annually in late winter and spring when water temperatures become more favorable for plant growth and the growing season continues through September (**Dobberfuhl 2007**; **Thayer, et al. 1984**). SAV beds, especially *Vallisneria*, are present year-round and are considered “evergreen” in Florida (**Sagan 2010**).

Sunlight is vital for good growth of submerged grasses. Sunlight penetration may be reduced because of increased color, turbidity, pollution from upland development, and/or disturbance of soils. Deteriorating water quality has been shown to cause a reduction in grass beds. This leads to erosion and further deterioration of water quality.

In addition to the amount of light, the frequency and duration of elevated salinity events in the river can adversely affect the health of SAV (**Jacoby 2011**). In lab studies, **Twilley and Barko 1990** showed that tape grass grows well from 0-12 parts per thousand of salinity and can tolerate water with salinities up to 15-20 parts per thousand for short periods of time. Also, SAV requires more light in a higher salinity environment because of increased metabolic demands (**Dobberfuhl 2007**). Finally, evidence suggests that greater light availability can lessen the impact of high salinity effects on SAV growth (**French and Moore 2003**; **Kraemer, et al. 1999**).

Dobberfuhl 2007 noted that, during drought conditions, there is an increase in light availability that likely causes specific competition between the grasses and organisms growing on the surface of the grasses (Table 4.1). Many of these epiphytic organisms block light and can be detrimental to normal growth of the tape grass. As a result, this fouling causes an increase in light requirements for the SAV (**Dunn, et al. 2008**).

Table 4.1 Submerged Aquatic Vegetation in the Lower St. Johns River

(Photo: SJRWMD)

Tape grass *(Vallisneria americana)*

- Teeth on edge of leaves
- Leaves flat, tape-like; 0.5–4 cm wide
- Leaves taper at tip
- No obvious stem
- Height: 4–90 cm
  (a small one can be confused with *Sagittaria subulata*)

(Photo: SJRWMD)

Water naiad *(Najas guadalupensis)*

- Leaf whorls not tightly packed
- Leaf pairs/whorls separated by large spaces on stem
- Leaves opposite, usually in pairs, sometimes in whorls of three
- Leave with teeth (must look closely); 2 mm wide

(Photo: SJRWMD)

Widgeon grass *(Ruppia maritima)*

- Leaves alternate, tapering at end
- Leaves thread-like; 0.5 mm wide
- Height: 4–20 cm

(Photo: Kerry Dressler)

Muskgrass *(Chara sp.)*

- Leaf whorls separated by conspicuous spaces
- Leaf not forked
- Leaves stiff and scratchy to touch
- Height: 2–8 cm

(Photo: SJRWMD)

Spikerush *(Eleocharis sp.)*

- No teeth on leaves
- Leaves round, pencil-like; 1–3 mm wide
- Leaves as broad at tip as at base
- Height: 1–5 cm

Water thyme *(Hydrilla verticillata)*

- Leaf whorls tightly packed
- Leaves opposite, in whorls of four to eight leaves
- Leaves with conspicuous teeth, making plant scratchy to the touch

(Photo: Kerry Dressler)

- Leaf tip pointed; leaves 2–4 mm wide
- Height: 5–15 cm

(Photo: SJRWMD)

Baby's-tears *(Micranthemum sp.)*

- Leaf whorls not tightly packed
- Leaf opposite, in whorls of three to four leaves
- No teeth on leaves
- Leaf tip rounded; 2–4 mm wide
- Height: 2–15 cm

(Photo: SJRWMD)

Sago pondweed *(Potamogeton pectinatus)*

- Leaves alternate; 0.5–4.5 cm wide
- No teeth on leaves
- Leaves long and narrowing with pointed tips
- Stems thread-like
- Height: 5–20 cm

(Photo: SJRWMD)

Small pondweed *(Potamogeton pusillus)*

- Leaves alternate; 0.5–3 mm wide
- No teeth on leaves
- Leaves long and narrow with blunted or rounded tips
- Stems thread-like
- Height: 5–20 cm

(Photo: SJRWMD)

Awl-leaf arrowhead *(Sagittaria subulata)*

- No teeth on leaves
- Leaves triangular, spongy; 3–8 mm wide
- Leaves taper at tip
- Height: 1–5 cm

(Photo: SJRWMD)

Horned pondweed (Zannichellia palustris)

- Leaves opposite
- No teeth on leaves
- Long narrow leaves with blunted tips
- Stems thread-like
- Often seen with kidney-shaped fruit
- Height: 1–8 cm

4.1.2.

4.1.3. Significance

SAV provides nurseries for a variety of aquatic life, helps to prevent erosion, and reduces turbidity by trapping sediment. Scientists use SAV distribution and abundance as major indicators of ecosystem health (**Dennison, et al. 1993**). SAV is important ecologically and economically to the LSJRB. SAV persists year round in the LSJRB and forms extensive beds which carry out the ecological role of "nursery area" for many important invertebrates, and fish. Also, aquatic plants and SAV provide food for the endangered West Indian manatee *Trichechus manatus* (**White, et al. 2002**). Manatees consume from 4-11% of their body weight daily, with *Vallisneria americana* being a preferred food type (**Bengtson 1981**; **Best 1981**; **Burns Jr, et al. 1997**; **Lomolino 1977**). Fish and insects forage and avoid predation within the cover of the grass beds (**Batzer and Wissinger 1996**; **Jordan, et al. 1996**). Commercial and recreational fisheries, including largemouth bass, catfish, blue crabs and shrimp, are sustained by healthy SAV habitat (**Watkins 1992**). **Jordan 2000** mentioned that SAV beds in LSJRB have three times greater fish abundance and 15 times greater invertebrate abundance than do adjacent sand flats. **Sagan 2006** noted that SAV adds oxygen to the water column in the littoral zones (shallow banks), takes up nutrients that might otherwise be used by bloom-forming algae (See Section 2.5, Algae Blooms) or epiphytic alga, reduces sediment suspension, and reduces shoreline erosion.

Over the years, dredging to deepen the channel for commercial and naval shipping in Jacksonville, has led to salt water intrusion upstream. The magnitude of this intrusion over time has not been well quantified (See Section 1.2.3 Ecological Zones). Further deepening is likely to impact salinity regimes that could be detrimental to the grass beds. This is especially important if harbor deepening were to occur in conjunction with freshwater withdrawals for the river (**SJRWMD 2012b**). On April 13, 2009, the Governing Board of the SJRWMD voted on a permit to allow Seminole County to withdraw an average of 5.5 million gallons of water a day (mgd) from the St. Johns River. Seminole County's Yankee Lake facility would eventually be able to withdraw up to 55 mgd. This initial permit from Seminole County represents the beginning of an Alternative Water Supply (AWS) program that could eventually result in the withdrawal of over 260 mgd from the St. Johns and Ocklawaha Rivers (**St. Johns Riverkeeper 2009**). The impact of water withdrawal on salinity was investigated by a team of researchers from the SJRWMD who participated in data collection, analyses, interpretation, and report writing. The National Research Council peer review committee provided peer review, and a final report was made available in early 2012 (**NRC 2011**). The National Research Council identified significant shortcomings, emphasizing the need for further research and analysis and the need to focus on a much safer and cost-effective alternative, water conservation. The Central Florida Water Initiative has recently released a draft Water Supply Plan that targets up to 155 mgd from the St. Johns River as an Alternative Water Supply. This plan prioritizes unsustainable surface water withdrawals over sustainable water conservation (**CFWI 2015**). Following are some of the concerns identified by the National Research Council peer review committee (**NAS 2015**), which include limitations in SJRWMD study:

- "In conducting the WSIS, District scientists found that the lack of basic data (e.g., certain kinds of benthos and fish information) and the inadequacy of basic analytical tools (e.g., on wetland hydrology and biogeochemical processes) limited what they were able to achieve and conclude."
- "…data needed to understand surface water–groundwater interactions and for the environmental impact analyses were not as readily available. In some cases data were very limited…. the lack of data impeded the progress of some workgroups and led to uncertainties about some of the WSIS conclusions."
- "…the relatively short period (ten years) of the rainfall record used for the hydraulic and hydrodynamic modeling and the assumption that it will apply to future climatic conditions is a concern."
- "…the workgroups did not appear to consider the possibility of back-to-back extreme events in their analyses, e.g., two or three years of extreme drought in a row, which the Committee considers to be reasonably likely future situations."
- "The Committee continues to be somewhat concerned with the basis for the final conclusion that water withdrawals of the magnitude considered in the WSIS will not have many deleterious ecological effects. In large part, this conclusion was based on the model findings that increased flows from the upper basin projects and from changes in land use (increases in impervious urban/suburban areas) largely compensated for the impacts of water withdrawals on water flows and levels….The generally poor quality of surface runoff from such land uses is well known."

- "…runoff resulting from increases in urban/suburban land area in the basin was assumed to affect watershed hydrology only….The modeling conducted by the District did not have a water quality component, and the District considered the potential ecological effects of significant increases in degraded stormwater runoff, as well as changes in the frequency distribution of stream flows in urbanized areas, to be outside the scope of the WSIS."
- "Although the District included water withdrawals from both the main channel of the St. Johns River and from the Ocklawaha River in its withdrawal scenarios, the WSIS focused only on potential effects of the withdrawals on the hydrology and ecology of the St. Johns River (and associated riparian wetlands). The Committee expressed concern from the outset of this study about the exclusion from the WSIS of potential effects of withdrawals on the Ocklawaha River (**NRC 2009**)."
- "Uncertainties about future conditions over which the District has no control (e.g., climate change, sea level rise, land use) also lead to concerns about the reliability of the conclusions."
- " If there is an extended drought in the future, when increased water supply demands have led to surface withdrawals, water suppliers might not be able to withdraw water from the river for months or even years on end. It is not obvious that this would be socially acceptable."

On May 10, 2011, JEA was granted a consolidated consumptive use permit to withdraw a base amount of 142 mgd of groundwater (based on JEA's demonstrated water demand in 2021). This amount can increase to 155 mgd by 2031 upon meeting several key conditions, and if JEA achieves reuse greater than the permit's conditions by providing more reclaimed water to other permitted groundwater users, the allocation could increase up to 162.5 mgd as these other groundwater uses are reduced or eliminated (**SJRWMD 2012b**).

4.1.4. Data Sources & Limitations

The SJRWMD has conducted year-round sampling of SAV from 1998 to 2011 at numerous stations along line transects of St. Johns River (1.25 miles apart) (**Hart 2012**). This monitoring program, which included water quality data collected at SAV sites, was suspended due to budget cuts. There are no new data available for 2012-2014. The routine field sampling performed provided information about inter-annual relative changes in SAV by site and region. Data evaluated in this report was for the years 1989, and 2000 through 2010. For maps of the individual transect locations see Appendix: 4.1.7.1.A-D.

The parameters used as indicators of grass bed condition were (1) mean bed length (includes bare patches) and grass bed length (excludes bare patches), (2) total percent cover by SAV (all species), and (3) *Vallisneria* percent cover. The data were broken down into six sections of the St. Johns River as follows: (1) Fuller Warren to Buckman, (2) Buckman to Hallows Cove, (3) Hallows Cove to Federal Point, (4) Federal Point to Palatka, (5) Palatka to Mud Creek Cove, and (6) Crescent Lake (Appendix: 4.1.7.1.A-D). The data set includes one of the most intense El Nino years (1998) followed by one of the most intense drought periods (1999-2001) in Florida history. Both of these weather phenomena exaggerate the normal seasonal cycle of water input/output into the river. Also, a series of shorter droughts occurred during 2005-2006 and 2009-2010. Normally, grass bed length on western shorelines tends to be longer than on eastern shorelines; and this is likely because of less wave action caused by the prevailing winds and broader shallower littoral edges compared to the east bank. Therefore, the shore-to-shore differences are most pronounced in Clay County-western shore sites and St. Johns County-eastern shore sites (**Dobberfuhl 2009**). For a list of grass species encountered within each section and a comparison of the variation among grass bed parameters, including canopy height and water depth, see Appendix: 4.1.7.1 A-D.

Because of the importance of color and salinity, rainfall and salinity levels were examined. Rainfall data were provided by SJRWMD (**Rao, et al. 1989**; **SJRWMD 2015a**) (Figure 4.1), the National Hurricane Center (**NOAA 2015d**), and the Climate Prediction Center (**NOAA 2015c**) (see Appendix: 4.1.7.1.E. for rainfall, hurricanes, and El Nino). Salinity data from 1991 to 2014 were provided by the Environmental Quality Division of the COJ. Water quality parameters are measured monthly at ten stations in the main stem of the St. Johns River at the bottom (5 m), middle (3 m), and surface (0.5 m) depths. Additional data on salinity from 1994 to 2011 came from the SJRWMD, and correspond with five specific SAV monitoring sites (Appendix: 4.1.7.1.F. Salinity). These data are discussed further in Section 4.4 (Threatened & Endangered Species). Note that "spot sampling" cannot be used to adequately match water quality parameters and grass bed parameters; because plants like *Vallisneria* integrate conditions that drive their responses. To evaluate such responses "high-frequency" data are required (**Jacoby 2011**). Moreover, information is limited about duration and frequency of elevated salinity events in the river and how that relates to the frequency and duration of rainfall. Also, there is limited information about the ability of SAV growing in different regions of the river to tolerate varying degrees of salinity. In 2009, the SJRWMD began to conduct research to evaluate this question by transplanting tape grass from one area to other areas in the river, thus exposing it to varying degrees of salinity for varying periods of time (**Jacoby 2011**). These same concerns are echoed by the Water Science and Technology Board's review of the St. Johns River Water Supply Impact Study (**NRC 2011** p5) – see a list of select findings under 4.1.5. Future Outlook.

4.1.5. Current Status & Trend

For the period 1989, and 2000 through 2007: The section of the St. Johns River north of Palatka had varying trends in all the parameters that usually increase and decrease according to the prevailing environmental conditions. For the period 2008-2011, the data showed a declining trend in grass bed parameters – this is in spite of some recovery in grass beds condition in 2011. Also, salinity was negatively correlated with percent total cover, and the proportional percent of tape grass (Appendix: 4.1.7.1.A-C). Aerial survey observations of manatees and their habitat in Duval County continue to indicate a general decline in grass bed coverage north of the Buckman Bridge (Bolles School to Buckman-east bank, and some parts from NAS JAX to Buckman-west bank, but not including Mulberry Cove).

There was a declining trend in all the parameters (2001-2007) south of Palatka and in Crescent Lake. From 2007-2009 the data suggested an increasing trend in all parameters. In 2010, data showed a declining trend, but in 2011 the trend was increasing again. Over the longer-term (2001-2011) there was a declining trend in grass bed length (Appendix: 4.1.7.2.C-D).

The availability of tape grass decreased significantly in the LSJRB during 2000-2001. This may be because the severe drought during this time caused higher than usual salinity values which contributed to high mortality of grasses. Factors that can adversely affect the grasses include excess turbidity, nutrients, and phytoplankton (see section 2.5 Algae Blooms). In 2003, environmental conditions returned to a more normal rainfall pattern. As a result, lower salinity values favored tape grass growth. In 2004, salinities were initially higher than in 2003 but decreased significantly after August with the arrival of heavy rainfall associated with four hurricanes that skirted Florida (Hurricanes Charley, Francis, Ivan and Jeanne). Grass beds north of the Buckman Bridge regenerated from 2002-2006 and then declined again in 2007 due to the onset of renewed drought conditions (**White and Pinto 2006a**). Drought conditions ensued from 2009-2010, leading to a further decline in the grass beds. Since 2010, rainfall returned to about normal levels and this was likely to help grass beds regenerate so some extent. Under normal conditions, SAV in the river south of Palatka and Crescent Lake is dynamic (highly variable), and significantly influenced by rainfall, runoff and water color (**Dobberfuhl 2009**). Taking everything into account, the current STATUS of SAV is *unsatisfactory*, and the TREND is *uncertain*.

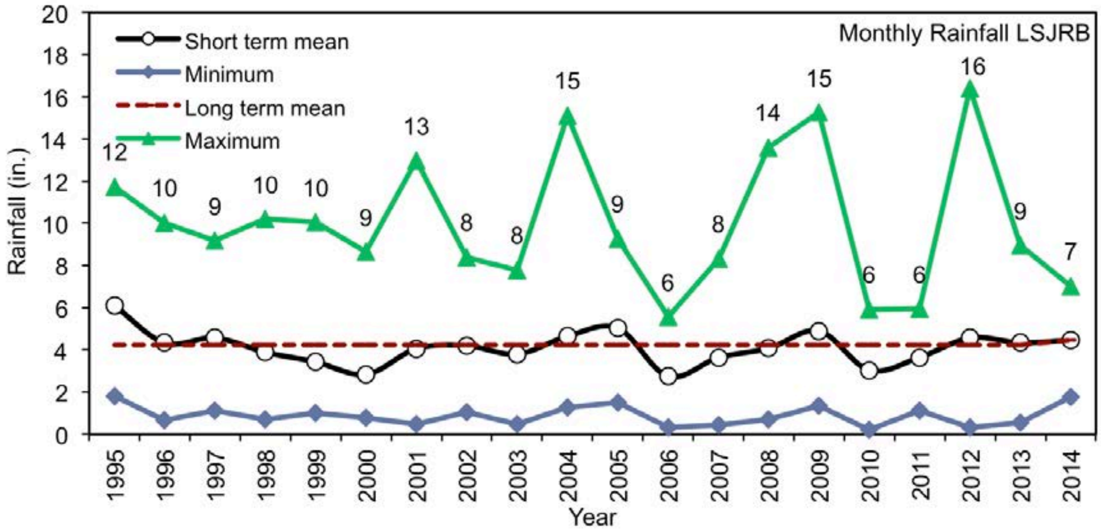


*Figure 4.1. Monthly rainfall maximum, minimum, long term and short term annual means for LSJRB. Data are for the period June 1995 to December 2014 (solid lines). Composite average of monthly rainfall for periods 1951-1960 and 1995-2014 were not significantly different (dotted line). Data source: **SJRWMD 2015a**. Note: The long-term mean is a composite mean that includes monthly rainfall for periods 1951-1960 from Rao et al. 1989 and monthly radar rainfall data from the district. The District provides rainfall data from its network of 75 rain gauges to a NexRad contractor. The contractor receives WSR-88D NexRad radar for several stations from the National Weather Service (NWS). The individual radar station data are combined into a radar mosaic that completely covers the SJRWMD territory with an array of pixels. Each pixel is approximately two kilometers by two kilometers in size that is four square kilometers in area. The contractor eliminates any discontinuities and ground clutter from the mosaic using proprietary geographic information system (GIS) algorithms. The contractor combines the gauge and radar data to calculate a gauge-radar ratio and applies the ratio in a radar calibration algorithm to derive a gauge-adjusted rainfall dataset that maintains the spatial signature of the radar data while incorporating the volume estimates from the rain gauges. The resulting gauge-adjusted radar rainfall data are delivered to the District and quality checked. After performing the quality checks, the gauge-adjusted radar rainfall data are uploaded to the District's Oracle database. These data are provisional and subject to change.*

4.1.6. Future Outlook

Continuation of long-term monitoring of SAV is essential to detect changes over time. Grass bed indices, along with water quality parameters, should be used to determine the current state of health. They can then be used to identify restoration goals of the SAV habitat, which will preserve and protect the wildlife and people who rely on the habitat for either food, shelter and their livelihood. Further indices of the health and status of grass beds should be developed that express the economic value of the resource as it pertains to habitat ecosystem services, fisheries and other quality-of-life indices such as aesthetics, recreation, and public health. As stated earlier, there are no new data available for 2012-2014. This monitoring program should be resumed as soon as possible especially in light of efforts to further deepen the port channel, and the pending environmental and habitat changes that are likely to ensue as a result of global warming and rising sea level.

Learning more about SAV response to drought and/or periods of reduced flow can provide crucial understanding as to how water withdrawals, dredging, and the issue of future sea level rise will affect the health of the ecosystem by adversely altering salinity profiles.

Select Water Supply Impact Study Findings (**NRC 2011**):

- "During Phase I, the District predicted that projected future water withdrawals could have dramatic consequences on SAV in some areas, especially where *V. americana* populations now fluctuate in the lower St. Johns River."
- "Although *V. americana* presumably could migrate further upstream, there is less shallow water area there, so a net loss of habitat is still expected."
- "..more spatially explicit predictions of the salinity increases in the littoral zone" were recommended and, "To enhance their monitoring program, the District should consider adding at least one continuous salinity monitoring station in the littoral zone during Phase II to detect short-term salinity excursions where *V. americana* is at risk."

- "The workgroup should also undertake more study of salinity tolerance of local populations from the St. Johns River, perhaps via mesocosm studies, in order to validate the values derived from the literature."
- "Finally, the workgroup might assess whether any other existing SAV species, for example *Ruppia maritima*, might be able to take the place of *V. americana* as a dominant macrophyte in the littoral zone."


Figure 4.2 A variety of wetlands can be found along the Lower St. Johns River Basin including salt marshes in the brackish, tidal coastal areas (left) and cypress-lined, freshwater, river swamps to the south of Jacksonville, Florida (right). (Photos: Heather P. McCarthy)

4.2. Wetlands

4.2.1. Description

Wetlands represent one of the most biologically diverse and productive systems on earth (**Myers and Ewel 1990**). The term *wetland* is broadly used to describe an area that is transitional between aquatic and terrestrial ecosystems. Within the LSJRB, these ecosystems include both coastal and freshwater wetlands (Figure 4.2). ***Coastal wetlands*** include all wetlands that are influenced by the tides within the St. Johns River watershed as it drains into the Atlantic Ocean (**Stedman and Dahl 2008**). The term *wetland* also includes non-vegetated areas like tidal sand or mud flats, intertidal zones along shorelines, intermittent ponds and oyster bars. ***Freshwater wetlands*** are typically inland, landlocked or further upstream in the Middle and Upper Basins of the St. Johns River. Wetland ecosystems described in this section are typically broken down into vegetation types based on physiognomy, or growth form of the most dominant plants: 1) forested wetlands and 2) non-forested wetlands. ***Forested wetlands*** are usually freshwater and include swampy areas that are dominated by either hardwood or coniferous trees. ***Non-forested wetlands*** can be marine, estuarine or freshwater, and are dominated by soft-stemmed grasses, rushes and sedges. Non-forested wetlands include wet prairies and mixed scrub-shrub wetlands dominated by willow and wax myrtle. The SJR represents, in Florida, one of the rivers with the highest headwater to stream length ratios, with 5.3 headwaters per km of river and a total of 886 headwaters (**White and Crisman 2014**). Headwater wetlands are associated with grassland/prairie, hardwood forest, and pine flatwood habitats (**White and Crisman 2014**).

4.2.2. Significance

Wetlands perform a number of crucial ecosystem functions including assimilation of nutrients and pollutants from upland sources. The estimated nitrogen removal of 187,765 Mt per year by SJR wetlands is valued at >$400 million per year for nitrogen and the estimated phosphorous removal of 2,390 Mt per year is valued at >$500 million per year (**Craft, et al. 2015**). Additionally, wetlands can help to minimize local flooding, and, thereby, reduce property loss (**Brody, et al. 2007**). Basins with as little as 5% lake and wetland area may have 40-60% lower flood peaks than comparable basins without such hydrologic features (**Novitski 1985**). In Florida between the 1991 and 2003, 48% of permits issued were within the 100-year floodplain, suggesting potential costs for recovery (**Brody, et al. 2008**). Wetlands also provide nursery grounds for many commercially and recreationally important fish; refuge, nesting, and forage areas for migratory birds;

shoreline stabilization; and critical habitat for a wide variety of aquatic and terrestrial wildlife (**Groom, et al. 2006**; **Mitsch and Gosselink 2000**).

4.2.3. The Science and Policy of Wetlands in the U.S.: The Past, the Present, and the Future

Since the 1970s when wetlands were recognized as *valuable* resources, accurately describing wetland resources and successfully mitigating for the destruction of wetlands have been ongoing pursuits in this country. During the last few decades wetland science and policy have been driven by a) calculating wetland loss, and b) determining how to compensate for the loss. The result has been adaptive management and evolving regulations.

Wetland mitigation was not initially a part of the Section 404 permitting program as outlined in the original 1972 Clean Water Act, but "was adapted from 1978 regulations issued by the Council on Environmental Quality as a way of replacing the functions of filled wetlands where permit denials were unlikely" (**Hough and Robertson 2009**). However, it was not until 1990 that the USACE and EPA actually defined mitigation. It was defined as a three-part, sequential process: 1) permit-seekers should first try to ***avoid*** wetlands; 2) if wetlands cannot be avoided, then permit-seekers should try to ***minimize*** impacts; and 3) if wetland impacts cannot be avoided or minimized, then permit-seekers must ***compensate*** for the losses.

4.2.3.1. The Past: A Focus on Wetland Acreage

During the 1980s-1990s, assessments of wetland losses (and the mitigation required as compensation) typically focused on ***acres*** of wetlands. In 1988, President G.H. Bush pledged "no net-loss" of wetlands. This pledge was perpetuated by President Clinton in 1992, and President G.W. Bush in 2002 (**Salzman and Ruhl 2005**). In order to ascertain whether this goal was being achieved or not, the USFWS was mandated to produce status and trends reports using the National Wetlands Inventory data. In 1983, the first report, *Status and Trends of Wetlands and Deepwater Habitats in the Conterminous United States, 1950s to 1970s,* calculated a net annual loss of wetlands during this time period equivalent to 458,000 acres per year (**Frayer, et al. 1983**). In 1991, the second report, *Status and Trends of Wetlands in the Conterminous United States, mid-1970s to mid-1980s,* reported a decline in the rate of loss to 290,000 acres per year (**Dahl and Johnson 1991**). In 2000, the USFWS released the third report, *Status and Trends of Wetlands in the Conterminous United States 1986 to 1997,* which concluded the net annual loss of wetlands had further declined to 58,500 acres per year (**Dahl 2000**).

4.2.3.2. The Present: A Focus on Wetland Functions

Although the USFWS reports marked the first comprehensive, scientific, and statistical attempts to *quantify* wetlands in the U.S., their value was recognizably limited because their results did not, and could not, evaluate the *quality* or *condition* of the acres of wetlands reported. In 2001, the National Research Council (NRC) concluded that "the committee is not convinced that the goal of no net loss for permitted wetlands is being met for wetland functions" (**NRC 2001**). This shifted the focus from wetland acres to wetland functions. The NRC pushed a new research agenda, which led to the refinement of scientific methods for assessing the ecological functions of wetlands. States called for expanded data collection and more comprehensive and standardized assessment techniques. By 2004, DEP had adopted uniform methods in Florida "to determine the amount of mitigation needed to offset adverse impacts to wetlands and other surface waters and to determine mitigation bank credits awarded and debited" (**DEP 2007b**). For the first time, the methods systematically and consistently considered wetland functions, and not just acreage.

In 2006, the fourth report by the USFWS, *Status and Trends of Wetlands in the Conterminous United States 1998 to 2004,* calculated for the first time a *net gain* of wetlands in the U.S. equivalent to 32,000 acres per year (**Dahl 2006**). This result was publicized, celebrated, scrutinized, and criticized. The central shortfall of the USFWS analyses was that wetland functions were not considered. This shortfall was briefly addressed in a footnote in the middle of the 112-page report: "One of the most important objectives of this study was to monitor gains and losses of all wetland areas. The concept that certain kinds of wetlands with certain functions (e.g., human-constructed ponds on a golf course) should have been excluded was rejected. To discriminate on the basis of qualitative considerations would have required a much larger and more intensive qualitative assessment. The data presented do not address functional replacement with loss or gain of wetland area" (**Dahl 2006**). The results of the 2006 report solidified the acceptance among scientists and policymakers that the simplistic addition and subtraction of wetland acres do not produce a wholly accurate portrayal of the status of wetlands. In short, any comprehensive evaluation of the status of wetlands needs to include a thorough consideration of what types of wetlands are being lost or gained and the ecosystem functions those wetlands provide.

Toward this end, publications began to emphasize that the USFWS's reported net gain of wetlands in the U.S. must be viewed alongside some important caveats and exceptions (**CEQ 2008**). For instance, some important types of wetlands were declining, although the overall net gain was positive. In 2008, USFWS and NOAA released an influential report entitled *Status and Trends of Wetlands in the Coastal Watersheds of the Eastern United States 1998-2004* (**Stedman and Dahl 2008**). This report calculated an annual loss of coastal wetlands at a rate of 59,000 acres per year (prior to Hurricanes Katrina and Rita in 2005). The report states: "The fact that coastal watersheds were losing wetlands despite the national trend of net gains points to the need for more research on the natural and human forces behind these trends and to an expanded effort on conservation of wetlands in these coastal areas" (**CEQ 2008**). The report emphasizes the important functions of coastal wetlands and the need for more detailed tracking of wetland gains and losses.

The positive trends reported in the earlier report did not persist. The *Status and Trends of Wetlands in the Coastal Watersheds of the Conterminous United States 2004 to 2009* states: "Wetland losses in coastal watersheds have continued to outdistance wetland gains, by an estimated 360,720 acres between 2004 and 2009 due primarily to silviculture and development…. **This rate of loss increased by 25 percent since the previous reporting period of 1998 to 2004**" (**Dahl and Stedman 2013**).

4.2.3.3. The Present: A Focus on Land Use Patterns

Land use patterns in the LSJRB have remained relatively unchanged between the years 2000 and 2009 (**SJRWMD 2014**). The land use categories of residential, pine plantations, and wetlands each contributed >10% of total acreage (Table 4.2). Greatest decreases in percent change (>1.5%) between the two years were in the land use categories: pine flatwood, pine plantations/forest regeneration and cabbage palm and swamp (Table 4.2).

Within 50 m of a waterway or lake in the LSJRB, 45% of total acreage was classified as wetlands/saltwater marsh and 29% of total acreage as residential in 2009 (**SJRWMD 2014**). Wetlands and residential use have a much larger proportion of acreage within 50 m of the river than in the entire LSJRB (Table 4.2). By comparison, proportion of pine plantations is much greater in the LSJRB away from a water body (Table 4.2). Riverside land use categories that contributed >10% of the total 12,762 acres in Duval County were military (38%), county lands (15%), and single family residential (13%) (**JCCI 2005**).

Table 4.2. Comparison of selected land use categories between 2000 and 2009 the Lower St. Johns River Basin, Florida (Source: SJRWMD 2010d; SJRWMD 2014).

LAND USE	% LSJRB		% ≤50 m OF WATER	
	2000	2009	2000	2009
Residential	12.6	13.7	30.0	29.4
Pine plantation, forest regeneration	24.5	22.2	3.9	4.5
Swamp, cabbage palm	11.9	9.6	32.3	29.1
Wetland (not saltwater marsh)	22.7	21.8	35.7	36.9
Saltwater marsh	1.0	0.9	8.9	7.8

4.2.3.4. The Present: A Focus on Wetland Mitigation Banking

The last decade has also been marked by the growing popularity of ***wetland mitigation banking***. To offset the impacts of lost wetlands caused by a permitted activity, the SJRWMD or USACE (with the consent of DEP) may allow a permit-holder to purchase compensatory mitigation credits from an approved mitigation bank. Wetland mitigation banks are designed to compensate for unavoidable impacts to wetlands that occur as a result of federal or state permitting processes (**NRC 2001**). By 2008, it was reported that mitigation banking accounted for >30% of all regulatory mitigation arising from the Section 404 permitting process (**Ruhl, et al. 2008**). Although more successful than previous approaches, mitigation banking has its own set of inherent problems and inadequacies. As **Salzman and Ruhl 2005** explain, "different types of wetlands may be exchanged for one another; wetlands in different watersheds might be exchanged; and wetlands might be lost and restored in different time frames."

According to **Salzman and Ruhl 2005**, "Despite all its potential shortcomings, wetland mitigation banks certainly remain popular. Credits in Florida are now trading anywhere from $30,000-$80,000 per acre. There clearly is demand and banks are still being created to supply it." Of course, the price that a permit-holder pays per mitigation credit varies by bank and time. For example, in October 2007, SJRWMD approved the Florida Department of Transportation (FDOT) to purchase 55 mitigation bank credits from the East Central Florida Mitigation Bank at a purchase price of $32,000 per credit with up to ten additional credits for $38,000 each for unexpected impacts (**SJRWMD 2007a**).

To facilitate mitigation banking within Northeast Florida, the SJRWMD has delineated mitigation basins. In most cases, mitigation credits can only be purchased within the same mitigation basin as the permitted project where wetland loss is expected. The SJRWMD mitigation basins closely resemble, but do not exactly align with the USGS drainage basins. Within the LSJRB, all or part of the following SJRWMD mitigation basins can be found: Northern St. Johns River & Northern Coastal, Tolomato River & Intracoastal Nested, Sixmile & Julington Creeks Nested, Western Etonia Lakes, St. Johns River (Welaka to Bayard), and Crescent Lake (**SJRWMD 2010d**).

The definition and use of mitigation bank service areas are explained below according to the SJRWMD (**SJRWMD 2010d**):

A mitigation bank's service area is the geographic area in which mitigation credits from the bank may be used to offset adverse impacts to wetlands and other surface waters. The service area is established in the bank's permit. The mitigation service areas of different banks may overlap. With three exceptions, mitigation credits may only be withdrawn to offset adverse impacts of projects located in the bank's mitigation service area. The following projects or activities are eligible to use a mitigation bank even if they are not completely located in the bank's mitigation service area:

- a) *Projects with adverse impacts partially located within the mitigation service area;*
- b) *Linear projects, such as roadways, transmission lines, pipelines; or*
- c) *Projects with total adverse impacts of less than one acre in size.*

Before mitigation credits for these types of projects may be used, SJRWMD must still determine that the mitigation bank will offset the adverse impacts of the project and either that:

- a) *On-site mitigation opportunities are not expected to have comparable long-term viability due to such factors as unsuitable hydrologic conditions or ecologically incompatible existing adjacent land uses; or*
- b) *Use of the mitigation bank would provide greater improvement in ecological value than on-site mitigation.*

In the LSJRB, 15 mitigation banks are active with permits processed by the USACE and 10 mitigation banks are active with permits processed by the SJRWMD (Table 4.3 and 4.4, **ERDC 2015; SJRWMD 2014**). These mitigation banks are typically located in rural areas with palustrine habitats. In the U.S., palustrine wetland habitats have the greatest loss in areal coverage due to conversion to agriculture and urban land use (**Brady and Flather 1994**). In 2014, thirteen mitigation banks showed permit activity (Table 4.3 and 4.4). Greens Creek was listed as suspended by USACE for timber harvesting and erosion-control modifications (**ERDC 2015**). In 2013, the new mitigation bank Northeast Florida Saltwater Marsh was approved by the USACE (**ERDC 2015**). Lower St. Johns and Town Branch are new mitigation banks listed with the SJRWMD and St. Marks Pond and Northeast Florida Saltwater Marsh have applied for permits (Table 4.4). Florida Department of Environmental Protection issued the Final Order to deny a permit for the Highlands Ranch to establish a mitigation bank on a 1,575 – acre site located in Clay County because of "success criteria in the proposed permit did not provide reasonable assurance of successful implementation of this approach" (**DEP 2013o**).

Table 4.3. Wetland Mitigation Banks Permitted by the USACE Serving the LSJRB, Florida (Source: ERDC 2015). Values in parentheses indicate credits reported in 2014 River Report.

MITIGATION BANK NAME	ACREAGE	CREDIT TYPE	CREDIT BALANCE AVAILABLE	WITHDRAWN	RELEASED	POTENTIAL
Barberville Mitigation Bank	366	Palustrine emergent, palustrine forested	2.8	13.1	15.9	63.7
Brick Road	2,945	Palustrine emergent, palustrine forested	64.3	0.3	64.6	504.0
Farmton	24,323	Palustrine	4004.6 (2412.3)	334.3 (327.8)	4338.9 (2740.1)	5102.6
Fish Tail Swamp	5,327	Palustrine forested	162.6 (180.6)	18.7 (0.7)	181.4	867.2
Greens Creek: **Suspended**	1,353	Palustrine forested	72.3	1.2	73.5	278.7
Highlands Ranch	1,581	Palustrine forested	2.1	0	2.1	70.37
Lake Swamp	1,890	Palustrine	41.3 (27.7)	16.0 (15.3)	57.4 (43.0)	215.3
Loblolly	6,240	Palustrine forested	1592.8 (996.3)	422.0 (417.4)	2014.8 (1413.7)	2507.5
Longleaf	3,021	Palustrine emergent, palustrine forested	842.7 (870.0)	183.9 (106.0)	1026.7 (974.4)	1026.7
Northeast Florida Saltwater Marsh	92.36	Estuarine intertidal, emergent	7.0	0	7.0	49.5
Northeast Florida Wetland	386	Palustrine	298.5 (315.4)	344.5 (327.6)	643.0	643.0
Peach Drive	57.3	Palustrine forested	32.3 (7.7)	16.4 (16.1)	47.6 (23.8)	47.6
Star 4	950.4	Palustrine forested	24.9 (25.0)	0.1 (0)	25.0	182.5
Sundew	2,105	Palustrine emergent, palustrine forested	24.6 (28.4)	24.2 (20.3)	48.75	931.4
Town Branch	432	Palustrine forested	10.8 (4.3)	0	10.8 (4.3)	56.26
Tupelo	1,525	Palustrine forested	461.0 (276.5)	97.7 (95.2)	558.7 (371.7)	643.95

Table 4.4. Wetland Mitigation Banks Permitted by SJRWMD Serving the Lower St. Johns River Basin, Florida (Sources: DEP 2013n; SJRWMD 2014) Values in parentheses indicate credits reported in 2014 River Report.

MITIGATION BANK NAME	ACREAGE	CREDIT TYPE	CREDIT BALANCE AVAILABLE	RELEASED	POTENTIAL
Greens Creek	4,201	Forested freshwater	42.4 (9.5)	254.0 (153.5)	405.4 (194.61)
Loblolly	6,247	Forested freshwater, general wetlands	33.7 (78.3)	1344.7 (1346.4)	1616.9
Longleaf	3,020	Forested freshwater	134.1 (437.6)	317.3 (54.8)	375.3 (54.8)
Nochaway	4,076	Forested freshwater	56.9 (459.7)	58.9	459.7 (58.9)
Northeast Saltwater Marsh- **application status**	93	Estuarine intertidal, emergent	5.8	7.2	47.7
Northeast Florida Wetland	774	General wetlands	13.8 (0)	394.9 (381.1)	394.9 (381.1)
Star 4	950	Forested freshwater	73.3 (48.8)	85.8 (51.5)	171.7
Sundew	2,107	Forested freshwater, herbaceous freshwater	19.1	192.0	698.3
Tupelo	1,524	General wetlands	0.38 (18.4)	459.7	459.7
St. Marks Pond- **application status**	759	Forested freshwater, herbaceous freshwater	31.5 (33.7)	33.7	134.8 (134.4)
Lower St. Johns	990	Forested freshwater	113.3 (116.0)	116.0	140.1
Town Branch	432	Forested freshwater	16.5 (14.9)	22.5 (16.0)	64.2

4.2.3.5. The Future: A Focus on Wetland Services

The future of wetland policies is rising out of the emerging science of ecosystem services (**Ruhl, et al. 2008**). As applied to wetlands, the *science of ecosystem functions* investigates how wetlands function in ecosystems (e.g., as nursery grounds, shelter, or food for wildlife). The emerging *science of ecosystem services* examines how wetlands serve human populations. As explained by **Ruhl, et al. 2008**, recent research documents that "wetlands can provide important services to local populations, such as air filtering, micro-climate regulation, noise reduction, rainwater drainage, pollutant treatment, and recreational and cultural values."

Ecosystem services research is just beginning to develop cost-effective methods to quantify wetland alterations. For example, wetland mitigation banking has led to a predominance of wetland banks in rural areas (**Ruhl and Salzman 2006**). In this case, the services provided by wetlands are taken from urban to rural environments. These services, like sediment capture, groundwater recharge, water filtration, and flood mitigation, have economic value associated with them. Calculating the dollar value of such services is a challenging, but not impossible, endeavor (Figure 4.3). The economic value of wetlands to retain stormwater surges or buffer shorelines was clear after Hurricanes Katrina and Rita hit the Gulf Coast of the U.S., where coastal wetlands have been substantially diminished (**Stedman and Dahl 2008**). **Brody, et al. 2007** examined wetland permits granted by the USACE in Florida between 1997 and 2001 and determined that "one wetland permit increased the average cost of each flood in Florida by $989.62."

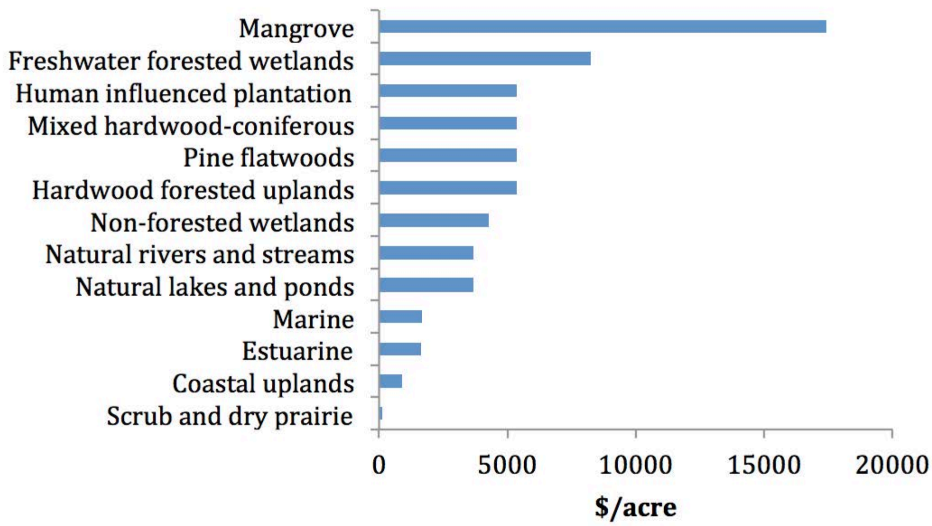


*Figure 4.3 Estimated value of ecosystem services by habitat (Source: **Brown and Shi 2014**).*

Likewise, the economic value of wetland-dependent recreation in northeast Florida is estimated in the range of $700 million per year (**Kiker and Hodges 2002**). The wetland-dependent activities with the greatest economic value to northeast Florida are recreational saltwater fishing ($301.6 million per year), followed by wildlife viewing ($226.5 million per year). Based on a survey results, Florida residents and tourists value outdoor recreation (>95% of 3,961 Florida residents and 2,306 tourists participated in outdoor recreation) and specifically saltwater beach activities (63%), wildlife viewing trips (49%), and fishing (46%) (**DEP 2013g**). In Florida, 2.9 million people fished, hunted, or viewed wildlife in 2006 (**USDOI and USDOC 2008**). The number of pleasure vessels recorded in Duval, St. Johns, Clay, Putnam, and Flagler is greater than 500,000 vessels (**SRR 2012**). Bird watchers spent an estimated $3.1 billion and fishers $4.3 billion in 2006 (**USDOI and USDOC 2008**). Canoeing and kayaking have become more popular, representing 14% of recreational activities in 2002 and 26% in 2011 (**DEP 2013g**). If these kinds of services are negatively impacted, the economic and social repercussions can be substantial.

Partially in response to the growing body of knowledge regarding wetland services, the USACE and EPA published a landmark overhaul of U.S. wetland regulations in April 2008 (**USACE and EPA 2008**). Not only did the rule consolidate the regulatory framework and require consideration of wetland functions, according to **Ruhl, et al. 2008**, "the new rule also for the first time introduces ecosystem services into the mitigation decision-making standards, requiring that 'compensatory mitigation…should be located where it is most likely to successfully replace lost…services.'" However, this requirement may be slightly ahead of the science – the necessary databases and scientific methods needed to fully consider the costs and benefits of ecosystem services do not yet exist. Although the new rule acknowledges that compensatory mitigation affects how wetland services are distributed and delivered to distinct human populations, there are few methods available for assessing these services quickly and reliably at any given site.

4.2.4. Data Sources on Wetlands in the LSJRB

4.2.4.1. Data Sources for Wetland Spatial Analyses

Nine GIS (Geographic Information System) maps that contain data on wetlands vegetation were available and analyzed. The GIS maps were created by either the Department of Interior USFWS or the SJRWMD from high-altitude aerial photographs (color infrared or black-and–white photos) with varying degrees of consideration of soil type, topographical and hydrologic features, and ground-truthing. In this analysis, each parcel of land or water was outlined and assigned a category, creating distinct polygons for which area (i.e., number of acres) can be calculated. These areas were used to calculate total wetlands and total acres within the LSJRB for each year available (Table 4.5).

Table 4.5. Comparison of Wetland Maps - Lower St. Johns River Basin, Florida.

GIS MAP ANALYZED	TOTAL WETLAND AREA IN LSJRB (ACRES)	TOTAL LAND/WATER AREA IN LSJRB (ACRES)
SJRWMD-corrected National Wetlands Inventory map (produced from 1971-1992 lumped data, processed by SJRWMD in 2001, 2003)	727,631	849,512 ACRES INCLUDING DEEPWATER. Non-wetland upland acres not specified in this map.
SJRWMD Wetland & Deep Water Habitats map (based on National Wetlands Reconnaissance Survey maps from 1972-1980, processed 1996 by SJRWMD, dated 2001)	870,576	3,110,209
SJRWMD Wetlands & Vegetation Inventory map (based on District's Wetlands Mapping Project 1984-2002, finished 2002, accuracy of wetland boundaries estimated at 80-95%)	441,072	2,208,172
SJRWMD Land Use/Land Cover map (based on 1973 data)	440,048	2,100,552
SJRWMD Land Use/Land Cover map (based on 1990 data)	435,662	2,605,247
SJRWMD Land Use/Land Cover map (based on 1995 data)	450,595	1,910,422
SJRWMD Land Use/Land Cover map (based on 2000 data)	444,467	1,851,447
SJRWMD Land Use/Land Cover map (based on 2004 data)	455,308	1,868,003
SJRWMD Land Use/Land Cover map (based on 2009 data)	452,315	1,903,789
* Lumped dates for maps result from the consolidation of aerial photographs taken during different years.		* 1.8 million acres is considered the accurate area of the LSJRB (according to the SJRWMD). Demonstrates that maps are not statistically comparable for total wetland area.

4.2.4.2. Data Sources for Wetland Permit Analyses

Within the LSJRB, there are two governmental entities that grant permits for the destruction, alteration, and mitigation of wetlands: 1) SJRWMD, and 2) U.S. Army Corps of Engineers (USACE). The differing regulatory definitions of wetlands used by Federal and State agencies are outlined in Appendix 4.2.A. At the regional level, the SJRWMD has posted a comprehensive online database of all mitigation bank ledgers (**SJRWMD 2010d**). At the national level, the USACE and EPA have made available a single online database to track mitigation banking activities called the *Regional Internet Bank Information Tracking System (RIBITS)* (**ERDC 2015**). Concurrently, the EPA and USACE have developed a GIS-enabled database to *spatially* track and map permits and mitigation bank transactions, which complement the RIBITS database (**Ruhl, et al. 2008**).

The wetland permit analysis conducted for this report reveals how the acreage of wetlands has changed over time according to the historical wetland permits granted through the SJRWMD Environmental Resource Permitting Program.

4.2.5. Limitations

4.2.5.1. Limitations of Wetland Spatial Analyses

The identification of vegetation type from an aerial photograph is an imperfect process. The metadata associated with the SJRWMD Wetlands & Vegetation Inventory map estimates the margin of error in wetlands delineation from aerial photographs to vary according to the type of vegetation being identified and range from 5- 20% (**SJRWMD 2010c**). The metadata states: "The main source of positional error, in general, is due to the difficulty of delineating wetland boundaries in transitional areas. Thematic accuracy: correct differentiation of wetlands from uplands: 95%; correct differentiation of saline wetlands from freshwater or transitional wetlands: 95%; correct differentiation of forested, shrub, herbaceous, or other group forms: 90%; correct differentiation of specific types within classes: 80%. Accuracy varies for different locations, dates, and interpreters."

In addition to interpretational errors, wetland maps do not accurately reflect wetlands habitats that vary seasonally or annually (e.g., the spatial extent of floating vegetation or cleared areas can be dramatically different depending on the day the aerial photo was taken). Aerial photographs pieced together to create wetlands maps may be of different types (high altitude vs. low altitude, color infrared, black-and-white, varying resolutions and varying dates). Sometimes satellite imagery is used to create wetlands maps, which is considered less accurate for wetland identification (**USGS 1992**).

Analyses are further limited by inconsistencies and shortcomings in the wetland classification codes used (e.g., wetland codes used in the SJRWMD Land Use/Land Cover map of 1973 were markedly different than codes used since 1990). Additionally, wetland classification codes do not always address whether a wetland area has been diked/impounded, partially drained/ditched, excavated, or if the vegetation is dead (although the National Wetlands Inventory adds code modifiers to address the impacts of man). Further, wetland mapping classification categories often do not differentiate between natural and manmade wetlands. For example, naturally occurring freshwater ponds may be coded identically with ponds created for stormwater retention, golf courses, fishing, aesthetics, water management, or aquaculture. Some maps classify drained or farmed wetlands as uplands, while others classify them as wetlands. An unknown number of additional discrepancies may exist between maps.

Lastly, most of the spatial information in wetlands maps has not been ground-truthed or verified in the field, but is based on analyses of aerial photographs and other maps.

4.2.5.2. Limitations of Wetland Permit Analyses

A shortcoming of the records of wetlands impacted through regulatory permitting processes is that they do not address total wetland acres in the region. Additionally, acreages recorded as mitigated wetlands do not always represent an actual gain of new wetland acres (e.g., mitigation acres may represent preexisting wetlands in a mitigation bank or formerly existing wetland acres that are restored or enhanced). Thus, a true net change in wetlands (annually or cumulatively) cannot be calculated from permit numbers with certainty.

Further, changing environmental conditions require that field verification of mitigated wetlands occur on a regular basis over long time periods. The actual spatial extent, functional success, health of vegetation, saturation of soil, water flow, etc. of mitigated wetlands can change over time. On-ground site visits can verify that the spatial extent of anticipated wetlands impacted (as recorded on permits) equals actual wetlands impacted and confirm the ecological functionality of mitigated wetlands.

4.2.6. Current Status

The current status of wetlands in Florida is considered UNSATISFACTORY, because a historical decrease in wetlands has been documented statewide. The current status of wetlands in the LSJRB is considered UNCERTAIN, because the reported statewide losses cannot be calculated with certainty for just the LSJRB.

4.2.6.1. Current Status of Wetlands in the LSJRB

The conclusions on the current status of wetlands in the LSJRB that can be gleaned from GIS maps are limited. Total wetland acres in the LSJRB cannot be determined with certainty from available data. The high margin of error associated with the delineation of wetlands from aerial photographs renders the wetlands maps unsuitable for total acreage calculations (see differences in total wetlands areas and total land/water areas calculated from maps listed in Table 4.2).

Based on the SJRWMD-corrected National Wetlands Inventory Map (thought to be most accurate and complete for this kind of information), 83% of all wetlands in the LSJRB are freshwater, and 3% are estuarine and marine wetlands (Figure 4.4). Freshwater wetlands are dominated mostly by freshwater forests, followed by freshwater unconsolidated bottoms and shores, including ponds. According to National Wetlands Inventory (**USFWS 1984**), Clay Co. and had approximately 59,771 acres, Putnam Co. had 111,198 acres, Duval Co. had 123,867 acres, Flagler Co. had 108,009, and St. Johns Co. had 114,693 acres of vegetated wetland.

Federal, state, local, and privately managed wetlands can be found in Florida conservation lands that include national parks, state forests, preserves and parks, wildlife management areas, mitigation banks, and conservation easements. Of the 887,148 acres that are managed within the LSJRB, 50% are federal lands, 45% state lands, 3% city lands, and 2% private as of December, 2014 (**FNAI 2015**). From a study of 20 conserved natural areas in Florida, ecosystem services were valued at $5,052 per acre (**Brown and Shi 2014**). For example, Pumpkin Hill Creek Preserve State Park was estimated in providing $6,169 per acre (**Brown and Shi 2014**).

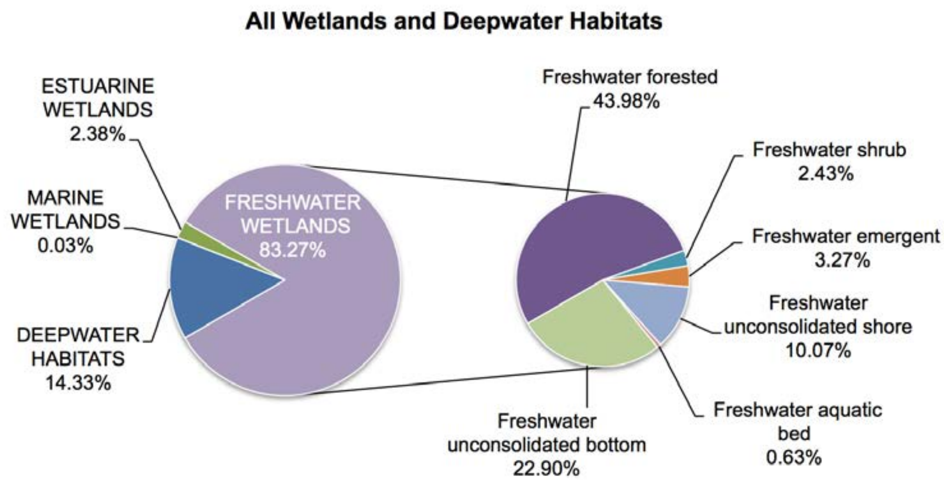


*Figure 4.4 The percentages of each wetland type in the Lower St. Johns River Basin, Florida (Source: **SJRWMD 2010c**).*

Stressors to wetland communities include land use, nutrients, pollutants, and invasive species. In addition changes in populations of endangered/sensitive species can be indicators of stressed wetlands. Below is a discussion of these stressors affecting the LSJRB:

LAND USE. Land use is a powerful predictor of wetland condition (**Reiss and Brown 2007**). In Florida, countless non-tidal wetlands <5 ha that were formerly in agricultural fields and pasture lands have since been developed for residential and commercial uses (**Reiss and Brown 2007**). For example, in 1960, the population density was 43 people/km^2 as compared to 183 people/km^2 in 2000 near Deland, FL (**Weston 2014**). Landscape Development Intensity (LDI) is an index that associates nonrenewable energy use (electricity, fuels, fertilizers, pesticides, irrigation) to wetland condition. Palustrine wetlands surrounded by multi-family residential, high-intensity commercial, and central business district had LDI scores of 9.19 to 10.00 as compared to pine plantation, recreational open space (low intensity) and pastures of 1.58 to 4.00 (**Reiss and Brown 2007**).

High LDI values can be predicted for areas in the LSJRB with multi-family residential and commercial land use. Residential land is prevalent along waterways, representing 29% of total acreage within 50 m of a waterway (Table 4.2). Surface drainage basins with residential land use can be plagued by low oxygen (e.g. Hogan Creek), fecal coliform (e.g. Cedar River, Ginhouse Creek, Hogan Creek, Goodbys Creek, Moncrief Creek, Black Creek, Pottsburgh Creek, and Broward River) (**SRR 2014**). Leaking septic tanks, stormwater runoff, and wastewater treatment plants contribute to fecal coliform. Commercial activities also ranked with high LDI values (**Reiss and Brown 2007**). In the LSJRB, Georgia-Pacific, power plants, shipping and maritime activities, and the US Department of Defense contribute to PAH, PCB, mercury, and nitrates in Rice Creek, Cedar River, and Ortega River (**SRR 2014**).

The extent of the surface drainage basin can exacerbate land use pressures (e.g. stormwater runoff). For example, the surface drainage basin Etonia Creek that includes the polluted Rice Creek covers 355 miles^2 (**Bergman 1992**). Connected surface drainage basins with a history of elevated fecal coliform levels and low oxygen include Julington Creek, Sixmile Creek, and Arlington River, covering approx. 260 miles^2 (**Bergman 1992**). Agriculture, although with a lower LDI (**Reiss and Brown 2007**) can contribute to nitrogen and phosphorous loading as is recorded from Deep Creek and Dunns Creek and cover approx. 100 miles^2 of surface drainage basin (**Bergman 1992; SRR 2014**).

NUTRIENTS. Residential and agricultural land use can contribute more nitrogen and phosphorous than other land use categories. For example, residential areas can release 2.32 mg N/L and 0.52 mg P/L as compared to agriculture (3.47 mg N/L and 0.61 mg P/L, respectively) and undeveloped/rangeland/forest (1.15 mg N/L and 0.055 mg P/L) respectively (**Harper and Baker 2007**). From a 2003-2009 study of water quality collected from 59 groundwater wells in the LSJRB, a relationship was evident between land use and groundwater (**Ouyang, et al. 2012**). Septic tank land use was represented by a mean of 7.4 mg/L nitrate/nitrite as compared to 0.04 mg/L in agricultural lands. By comparison, calcium, sodium, chlorine, and sulfate had more than twice the values in agricultural lands (agriculture: 85.9, 148.8, 318.8, and 233.1mg/L; septic tank land use: 34.5, 23.2, 36.5, and 58.8 mg/L, respectively; **Ouyang, et al. 2014**). Managed plantations that use nitrogen and phosphorous excessively can be a source of nutrient loading to nearby tributaries that can be measured from weeks to years following application in sediments and water column (**Shepard 1994**). In addition, nutrient-laden waters from wastewater treatment spray fields can travel via the aquifer and contribute to nutrient loading far from the source, as has been recorded in Wakulla Spring from Tallahassee's wastewater reuse facility (**Kincaid, et al. 2012**).

Compared to 1998, total nitrogen levels have declined between 9 and 33% in the marine/estuarine and freshwater river regions, respectively (**SRR 2013**). A similar pattern was reported for total phosphorous concentrations in the marine/estuarine river region with a decline of 13% relative to estimates from 1998 (**SRR 2013**).

Sediments retain nitrogen and phosphorous which can be released back into the water column. During periods of anoxic conditions due to algal blooms, Malecki, *et al.* reported that 21% of total P load and 28% of total N load came from the sediments in the LSJR (**Malecki, et al. 2004**). Dissolved reactive phosphorous released from the sediments was 37 times lower (0.13 mg per m^2 per day) than during aerobic conditions (4.77 mg per m^2 per day) (**Malecki, et al. 2004**).

The presence of nutrients in combination with herbicides such as atrazine has been shown to have negative impacts on the native *Vallisneria americana* (**Dantin, et al. 2010**). Submerged aquatic vegetation (SAV, e.g. *Vallisneria americana*) provides food and refuge for shrimp, blue crabs, and a variety of other fauna.

POLLUTANTS. Arsenic is present in LSJRB sediments. In Naval Station Mayport, spoils from dredging of the basin were used to fill in wetlands and low-lying areas (**Fears 2010**). These dredged materials are concentrated in arsenic (**Fears 2010**). Arsenic contamination has also been documented in golf course soils (5.3 to 250 ppm, with an average of 69.2 ppm) due to herbicide applications to turf grass (81 golf courses from the northeast, 1086 surveyed in Florida - **Ma, et al. 2000**). Leaching of arsenic is further exacerbated by the presence of phosphorous, commonly applied in fertilizer. Many of these golf courses have water bodies or are near wetlands, streams, and rivers (**Ma, et al. 2000**). **Ouyang, et al. 2014** reported greater arsenic values in the groundwater associated with agriculture (4.3 μg/L) and wastewater sprayfield (5.6 μg/L) land use as compared to undeveloped forest lands and septic tank land use (0.6 and 1.3 μg/L, respectively) in the LSJB.

Wading birds and other fauna that forage in wetlands are at risk of bioaccumulation of heavy metals. For example, mercury has been reported in the Broward and Trout Rivers. **Ouyang, et al. 2012** estimated an average annual mercury load of 0.36 g ha^{-1} year^{-1} within the Cedar and Ortega watershed (254 km^2). More troubling are discharges of mercury by the St. Johns River Power Park and Northside Generating Station which discharged 77% of the total mercury discharges in the LSJR basin as of 2011 (**SRR 2013**). Salt marshes are sinks for metals (**Leendertse, et al. 1996**). **Giblin, et al. 1980** found that metals in *Spartina alterniflora* detritus were taken up by fiddler crabs, and metals can be concentrated in bivalves near contaminated sites (**Leendertse, et al. 1996**). **Burger, et al. 1993** reported mean lead concentrations of 3,640 ppb dry weight in young wood storks from Dee Dot colony, demonstrating the availability of lead contamination and bioaccumulation from prey items.

HYDROLOGIC MANIPULATION. Many of the mitigation banks in the LSJRB were formerly pine plantations. Hydrology in forest plantations is typically modified to minimize surface waters (**Shepard 1994**) that can then impact non-tidal wetland diversity and sediment and nutrient loading to nearby waterways. Erosion in plantations adds to suspended sediments in drainage waters and connecting waterways (**Shepard 1994**). In lowland forested habitats, storm water is retained in the forest and runoff occurs after the groundwater table reaches the surface (**Sun, et al. 2000**). When trees are harvested, the groundwater table rises particularly during dry periods, a phenomenon that can continue over a period of years (**Sun, et al. 2000**). The decrease in evapotranspiration rates with the loss of trees is responsible for this rise in the water table (**Shepard 1994**).

Bernardes, et al. 2014 raised the issue of water withdrawal affecting wetlands in northeastern Florida. Depressional wetlands are typically relict sinkholes. The Florida aquifer system is crisscrossed with fractures along which groundwater can travel. Mine pits create ponds where aquifer and groundwater accumulates and thus deprives other areas of water for recharging and supporting vegetation. Where mining-related withdrawal has occurred, wetlands in nearby mitigation banks and conservation areas have dried out with the potential of becoming sinkholes. For example the DuPont Trail Ridge Mine is in close proximity to many of the mitigation banks listed in Table 4.3 and conservation areas (e.g. Camp Blanding, Cecil Field) that wetland permitees use to mitigate wetland alteration. Water quality, hydroperiods, and water availability would be impacted at these mitigation sites (**Bernardes, et al. 2014**).

INVASIVE SPECIES. The most damaging invasive plant species have the capacity to do one or more of the following: reproduce and spread successfully, compete successfully against native species, proliferate due to the absence of herbivore or pathogen that can limit their populations, and alter a habitat (**Gordon 1998**). Invasive species can modify a wetland habitat by changing geomorphology (erosion, soil elevation, water channel), hydrology (water table depth, surface flow), biogeochemical cycling (nutrient pathways, water chemistry, nitrogen fixation), and disturbance regime. *Eichhornia crassipes* and *Pistia stratiotes* are reported to impact siltation rates, *Panicum repens* stabilizes edges of waterways, *Hydrilla verticillata* slows water flow where abundant, and *E. crassipes*, *P. stratiotes*, and *H. verticillata* alter water chemistry (dissolved oxygen, pH, phosphorous, carbon dioxide, turbidity, and water color) (**Gordon 1998**).

Where invasive plant species are dominant, native weedy species also proliferate (**Gordon 1998**). In a 2002 study of depressional non-tidal wetlands in Florida, macrophyte diversity and the percentage of native perennial species in urban environments were lower than in locations away from urban environments (**Reiss 2006**). Species that were considered the most tolerant to disturbance intensity in depressional marshes included *Alternanthera philoxeroides*, *Cynodon dactylon*, *Mikania scandens*, *Panicum repens*, and *Schinus terebinthifoilius* (**Cohen, et al. 2004**). From a survey of 74 non-tidal depressional wetlands in Florida, greater plant species richness was associated with more disturbed sites and fewer species in undisturbed and oligotrophic conditions (**Murray-Hudson, et al. 2012**). Ruderal or weedy species are likely to tolerate changes in the wetland-upland boundary and variability in soil saturation and water depth and extent. The authors also showed that the outer zone adjacent to the upland border of a depressional wetland with high numbers of exotics would also have a high number of exotics throughout the wetland. This pattern was true for sensitive species as well, indicating that the condition of the wetland could be predicted by the richness of suites of species along the outer band of the wetland (**Murray-Hudson, et al. 2012**).

ENDANGERED/SENSITIVE SPECIES. Urbanization, habitat encroachment and increased recreational activities can negatively impact breeding populations of amphibians, reptiles, and birds. Development that alters and/or fills headwaters and streams negatively impacts habitat connectivity for many stream and wetland-dependent organism in the SJR watershed (**White and Crisman 2014**). Animals that require a variety of wetland types would be negatively impacted by chemical pollutants and turbidity that limits prey availability. Sensitive species associated with wetlands include the Striped newt (*Notophthalmus perstriatus*) that is listed as a candidate species for protection; and the flowering plants Chapman rhododendron (*Rhododendron chapmanii*), Okeechobee gourd (*Cucurbita okeechobeensis*), and Rugel's pawpaw (*Deeringothamnus rugelii*) that are listed as endangered in counties of the LSJRB (**USFWS 2014b**). Other threatened and endangered species are found in Section 4.4. Under review, the candidate Black Creek crayfish is found in Doctors Lake and Rice Creek, both affected by contamination (**USFWS 2014b**, **SRR 2014**).

Urbanization and subsequent habitat loss and alterations can result in negative interactions between humans and wildlife. For example, the Wildlife Service is called in to disperse or dispatch a variety of animals. Between the years 2006 and 2011, gulls, egrets, and herons represented 57% of the 4,407,393 animals that the agency dispersed through a variety of measures in Florida (e.g. firearms, pyrotechnics, pneumatics, and electronics) (**Levine and Knudson 2012**). Comparing the Christmas Bird Counts in years 2000 and 2011 to 2014 from a marsh near Clapboard Creek, the numbers of brown pelicans, white ibis, and laughing gulls have increased substantially from 2000. The numbers of brown pelican and bald eagle have decreased since 2011, but numbers of the federal listed threatened piping plover tripled since 2013 and the federal listed endangered wood stork has remained stable (Table 4.6, **Audubon 2015**). Changes in counts may represent habitat modifications in nearby areas.

Table 4.6. Christmas Bird Counts of Selected Species from Jacksonville Marsh Site in 2000-2014. SSC - species of special concern, ST- state listed, threatened, FT- federal listed, threatened, FE- federal listed, endangered (Source: Audubon 2015).

SPECIES	STATUS	2000	2011	2012	2013	2014
Brown pelican	SSC	634	2000	1250	1100	800
American oystercatcher	SSC	13	14	7	8	6
Laughing gull		512	3100	950	800	1100
Bald eagle		18	34	35	32	21
Piping plover	FT	24	8	4	6	18
Snowy egret	SSC	307	391	175	175	400
Wood stork	FE	120	128	105	120	100
Black skimmer	SSC	8	10000	540	350	600
Tricolored heron	SSC	128	67	60	50	100
Little blue heron	SSC	54	93	75	80	100
White ibis	SSC	352	1000	400	200	900
Roseate spoonbill	SSC	1	34	5	6	13
Osprey	SSC	82	120	130	100	100

Least terns are migratory birds that require sandy or gravel habitats with little vegetation for nesting. Rooftop nesting sites have become more common due to habitat loss. Large rooftop populations have been recorded at NAS Jacksonville (**Jackson 2013**). In Florida, Wildlife Service Agency had been called upon to disperse 273 least terns in 2011, indicating negative interactions with humans (**Levine and Knudson 2012**).

Wood storks (endangered) nest in the LSJR and feed on fish among other animals, requiring 450 lbs. of fish per pair during the nesting season (**SRR 2012; SRR 2014**). They require shallow pools that dry up to help concentrate fish prey. During extended periods of drought, wood stork numbers decrease. Currently, populations are considered stable with respect to numbers of nesting pairs. Jacksonville Zoo and Gardens (100 nests in 2011), Dee Dot (55 nests in 2011), and Pumpkin Hill were active in 2009 but since then data have been unavailable or the site inactive, respectively (**SRR 2014**). Between the years 2000 and 2011, numbers of wood storks remained unchanged in a marsh near Clapboard Creek (Table 4.6). In Florida, Wildlife Service has been called upon to disperse 270 wood storks in 2008-2011, indicating negative interactions with humans (**Levine and Knudson 2012**).

The following trends in wetlands within Florida and certain sections of the LSJRB are also notable:

- In Florida, the conversion of wetlands for agriculture, followed by urbanization, has contributed to the greatest wetland losses (**Dahl 2005**).
- The Upper Basin (the marshy headwaters of the St. Johns River) has experienced substantial historical wetland loss, and by 1983, it was estimated that only 65% of the original floodplain remained (**SJRWMD 2000**).
- **Hefner 1986** state that "over a 50-year period in Northeast Florida, 62 percent of the 289,200 acres of wetlands in the St. Johns River floodplain were ditched, drained, and diked for pasture and crop production (**Fernald and Patton 1984**)."
- According to **DEP 2002**, "the 1999 District Water Management Plan notes seven to 14 percent losses of wetlands in Duval County from 1984 to 1995, according to National Wetlands Inventory maps."
- In 2012-2013, the SJRWMD reported a loss of 380.7 wetland acres as compared to 14.5 acres created, 2,268.6 acres preserved, and 660.1 acres enhanced (**DEP 2014a**).

4.2.6.2. Current Status of Wetlands in Florida

A discussion of wetland status in the LSJRB is incomplete without an evaluation of wetlands within a broader, historical context. Although wetlands maps do not reveal with any statistical certainty how many acres of wetlands in the LSJRB have been gained or lost over time, there are reliable historical records in the literature that estimate how many wetland acres have been lost *throughout the state of Florida* over time. A literature search was conducted to compile comparable and quantifiable estimates of historical wetland change in Florida over time. Because data occurring within just the LSJRB could not be extracted from statewide data, information for the whole state of Florida was evaluated and compiled in Appendix 4.2.B.

Prior to 1907, there were over 20 million acres of wetlands in Florida, which comprised 54.2% of the state's total surface area. By the mid-1950s, the total area of wetlands had declined to almost 15 million acres. The fastest rate of wetland destruction occurred between the 1950s and 1970s, as the total area of wetlands dropped down to 10.3 million acres. Since the mid-1970s, total wetland area in Florida appears to have risen slightly. Net increases in total statewide wetlands are attributed to increases in freshwater ponds, such as manmade ponds created for fishing, artificial water detention or retention, aesthetics, water management, and aquaculture (**Dahl 2006**). The average of all compiled wetlands data in Florida revealed that the state retained a total of 11,371,900 acres by the mid-1990s (occupying 30.3% percent of state's surface area). This translates into a cumulative net loss of an estimated 8,940,607 acres of wetlands in Florida since the early 1900s (a loss of 44% of its original wetlands) (Appendix 4.2B).

4.2.7. Current Trends in Wetlands in the LSJRB

Trends in wetlands can only be ascertained from sequential, time-series data. The only dataset of this type regarding wetlands within the LSJRB is contained within Land Use/Land Cover maps from the SJRWMD. These Land Use/Land Cover maps include spatial data on wetland types and were produced in 1973, 1990, 1995, 2000, 2004, and 2009.

4.2.7.1. Trends in Total Wetlands Acreage

Acres per year of wetlands derived from the SJRWMD Land Use/Land Cover maps are not comparable or statistically robust in order to establish trends in total wetland acreage over time. The lack of comparability between years stems from differences in the techniques, scale, and wetlands interpretation. Therefore, the current trend in total wetland acreage within the LSJRB is considered UNCERTAIN.

4.2.7.2. Trends in Wetland Vegetation

Although the total wetland acreage cannot be statistically compared from year to year, the relative contribution of different wetland types can be statistically compared with an acceptable degree of reliability. These comparisons attempt to assess how the quality of wetlands in the LSJRB might have changed over time.

Most categories of wetlands used in the SJRWMD Land Use/Land Cover maps were not consistent over the years. Notably, the categories used in 1973 were markedly different from the categories used in the 1990-2004 maps (see Appendix 4.2.C.).

When wetland codes are grouped into two broad categories (forested wetlands and non-forested wetlands), significant trends are noted. There appears to have been a shift in the composition of wetland communities over time from forested to non-forested wetlands (Figure 4.5). Forested wetlands comprised 91% of the total wetlands in 1973, and constituted only 74% of total wetlands in 2009. **Brown and Shi 2014** estimated freshwater forested wetlands represent twice the ecosystem value as non-forested wetlands (Figure 4.3). Because forested wetland categories changed over the years, specific categories that declined between 1973 and 2009 cannot be identified (Appendix 4.2.C.). However, between 2000 and 2009, almost every forested wetland category had decreased, with cabbage palm hammock and pond pine having the greatest decreases. By comparison, non-forested wetlands comprised 9% of the total wetlands in 1973 and 26% in 2009. Wet prairies and mixed scrub-shrub wetland categories contributed to observed increases (Appendix 4.2.C.)

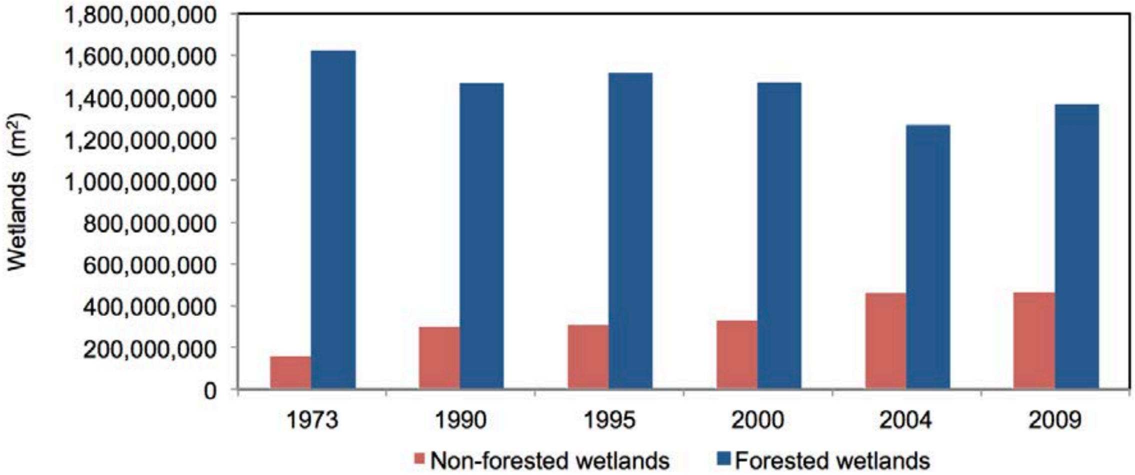


Figure 4.5 Forested Wetlands and Non-forested Wetlands in the Lower St. Johns River Basin based on Land Use/Land Cover Maps (SJRWMD).

4.2.8. Wetland Permit Trends in the LSJRB

The SJRWMD processes environmental resource permits that may impact wetlands and surface waters (**SJRWMD 2014**). In general, these projects were located in mixed hardwood wetlands. During 2014, 56 SJRWMD-processed permits that impacted wetland were issued and were each ≤101 impacted wetland acres. The three permits >50 average wetland impacted acres in 2014 were Florida Department of Transport projects (**SJRWMD 2014; SJRWMD 2015b**). Between the years 2000 and 2014, the majority of issued permits were for <10 average impacted wetland acres in a project, based on SJRWMD permitting records (Figure 4.5). Previously, the SJRWMD permit database reported mitigated acreage and now only report impacted wetland acreage (**SJRWMD 2015b**). Those permits for residential and small business land use modifications highlight the challenges with wetland mitigation. Incremental wetland conversions result in cumulative impacts at the landscape level. In 2014, issued permits proposed to impact 224 wetland areas that were on average 2.4 acres each. Another 105 impacted wetlands areas did not require mitigation and were each 0.4 acre on average (**SJRWMD 2015b**).

Wetlands become fragmented across the urban landscape and different habitats occur within and surrounding project sites (**Kelly 2001**) which then impacts wetland function and community composition (**Faulkner 2004**). If wetlands are few and far between, then travelling amphibians and other animals are exposed to pollutants and death on roadways (**Faulkner 2004**). Even smaller wetlands <0.2 ha contribute to local diversity (e.g. juvenile amphibians, **Semlitsch and Bodie 1998**). Permits for modifying small wetlands are the largest in numbers and yet the contribution of these wetlands to local diversity remains undocumented (**Semlitsch and Bodie 1998**, Figure 4.6). Permits are given to individuals and are site specific, but cumulative impacts due to the number of conversions at the landscape scale are not addressed.

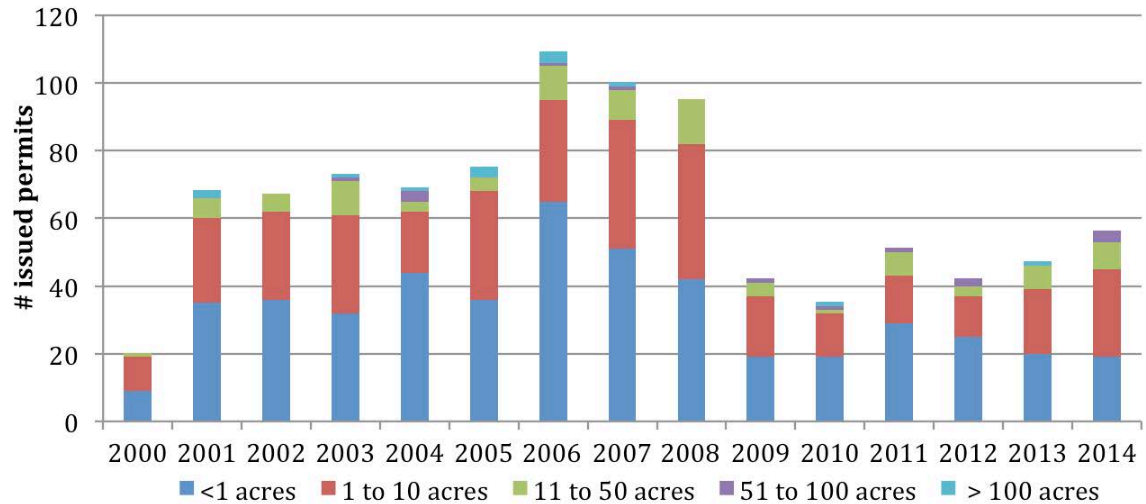


*Figure 4.6 Numbers of SJRWMD permits per project impacted wetland acreage from 2000 to 2014 (**SJRWMD 2014**).*

Based on SJRWMD permit records, the methods used to mitigate wetlands have changed over time (Appendix 4.2.D.). During the early 1990s, wetland areas were most commonly mitigated by the creation of new wetlands or through wetland restoration. During the 2000s, relatively few wetlands were created or restored with most mitigation occurring through the preservation of uplands/wetlands (Figure 4.7). In 2014, 3 of the 56 issued permits proposed to create wetlands and 2 permits proposed to restore 2.8 acres (Table 4.7) (**SJRWMD 2015b**). In addition, wetland mitigation is likely to occur in mitigation banks away from the project site. In 2014, permitees of 20 projects applied for a total of 65.1 credits and 22 projects were permitted for on-site mitigation (Table 4.8) (**SJRWMD 2015b**).

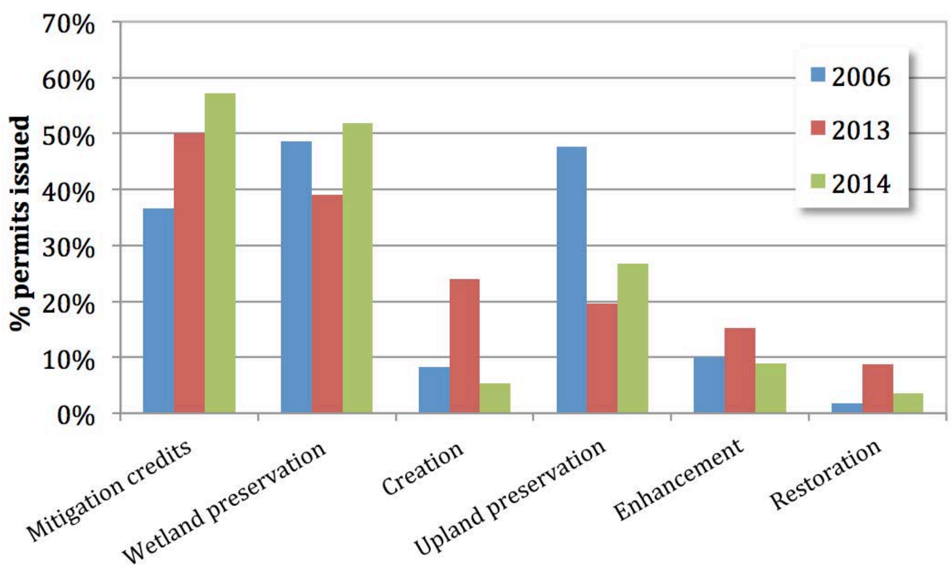


*Figure 4.7 Percentage of issued permits that opted for purchasing mitigation credits, wetland preservation, creation, upland preservation, or enhancement in the years 2006, 2013, and 2014. Because permittees may opt to use more than one type of mitigation for a project, total percentages per year will exceed 100% (**SJRWMD 2015b**).*

4.2.8.1. Trends in Wetland Acreage Impacted/Mitigated by Permits Granted by USACE

For a complete analysis of wetlands impacted and mitigation in the LSJRB, data needed from the USACE would include the location, total acres, type of vegetation, maturation/stage of wetland, wetland functions replaced, and wetland services replaced. A similar data deficit was found by the NRC, which concluded that "data available from the Corps were not adequate for determining the status of the required compensation wetlands" (**NRC 2001**).

In 2014, mitigation banks were used more than preservation, creation, enhancement, or restoration mitigation (Figure 4.7). The number of permits issued that proposed to purchase mitigation credits was lower in 2006 (110 permits and 773 wetland impacted acreage) as compared to 2014 (56 permits and 268 wetland impacted acreage), (Figure 4.6). The mean ratio of mitigation credit per acreage of impacted wetland was greater in 2006 (2.1, n = 29 permits) than in 2014 (0.37, n = 20 permits) for those projects that used mitigation banks as the only type of wetland mitigation. The percentage of permitted projects that planned for wetland preservation was greater in 2014 compared to 2006 and 2013 (Figure 4.7). However, the total acreage for preservation, creation, and enhancement to wetland impacted acreage was greater in 2006 (due primarily to Rivertown development) as compared to 2014 (due primarily to 52 acres in the Cecil Commerce Center, and 88 acres in the Tamaya residential development that had begun in 2005, ceased in 2008-2012, and has now resumed; Table 4.7) (**SJRWMD 2015b**).

Table 4.7. Acreage comparison in wetland mitigation for permits issued in 2006, 2013, and 2014 that required mitigation (SJRWMD 2015b).

TYPE OF MITIGATION	2006 110 ISSUED PERMITS	2013 47 ISSUED PERMITS	2014 56 ISSUED PERMITS
Wetland preservation	4853	691	862
Upland preservation	1001	139	114
Creation	98	28	60
Enhancement/restoration	7539	30	113

The USACE has proposed to modify Mile Point for navigational safety and to use the dredge spoils for restoring 53 acres of wetland habitat to Great Marsh Island. Loss of 8.15 acres of salt marsh at Helen Cooper Floyd Park would be mitigated at Great Marsh Island that has experienced erosion and breakthrough. USACE notes that there are no salt marsh mitigation banks in northeast Florida (**USACE 2011**). In addition, up to 26.2 acres of salt marsh would be restored. The salt marsh species would be planted across 8 (costing $465,888) to 53 (costing $3,029,701) acres, depending on the plan chosen. Another 8 acres of restored marsh would be from dredging of the proposed Flow Improvement Channel in Chicopit Bay. In addition, deploying the spoils at Great Marsh Island would save $9,056,000 as compared to disposing at Buck Island (**USACE 2011**).

The Supreme Court ruled on the Koontz v. St. Johns River Water Management District case (**USSC 2013**). Koontz, a Florida landowner had challenged the terms set by the SJRWMD for filling in wetlands on his property near Orlando (**Sommer 2013**). The SJRWMD had proposed a plan for mitigation on district lands rather than on-site as proposed by Koontz. Koontz withdrew his application, the permit was denied, and the lawsuit was filed. The Supreme Court ruled in favor of Koontz. There is concern that regulators may be less likely to negotiate with land developers to avoid possible lawsuits and instead, may deny permits (**Sommer 2013**).

4.2.9. Future Outlook

HIGH VULNERABILITY. The total spatial extent of wetlands negatively impacted through the SJRWMD permit process is increasing each fiscal year and is likely to increase with the improvement in the national and state economies. These impacts are magnified by the losses of wetlands permitted by the USACE (the evaluation of these Section 404 permits is limited in this study). Many remaining wetlands are susceptible to alteration and fragmentation due to growing population pressures in northeast Florida. Urbanization at the landscape level has a direct impact on wetland communities. Incremental filling of depressional ponds in addition to developing along waterways have the consequence of altering local hydrology, adding nutrients and heavy metals to the sediments and water column, bioaccumulation of heavy metals up the food web, and increasing the number and coverage of nuisance and invasive species. Isolated wetlands can retain 1,619 m^3 water/ha, on average, from models developed for Alachua County, FL, wetlands (**Lane and D'Amico 2010**). The potential for flooding, hydrologic alterations, and pressures on species diversity will continue with the loss of wetlands in the LSJRB.

In addition to development and withdrawals, tidal wetlands will be impacted by sea level rise. Tidal wetlands in the river are unlikely to outpace sea level rise estimated at 3 mm/year (**Weston 2014**) due to inability of marsh vegetation to accrete organic material at faster rates. In addition, delivery of fluvial suspended sediments is relatively low in the St Johns River, compared to other US rivers (**Weston 2014**). Turbidity in the main stem is improving, indicating that sediment export to the tidal wetlands is low (**SRR 2013**). Coastal wetlands may be less impacted by sea level rise. Contrary to expectations of coastal erosion with sea level rise and disruption of longshore drift with dredging activities, shorelines along Duval and St Johns counties have been advancing since the 1800s (**Houston and Dean 2014**). On-shore sediment deposition is the likely mechanism and may help buffer erosion and sediment transport due to sea level rise in the future (**Houston and Dean 2014**).

Wetlands in the LSJRB will be affected in the future due to surface water withdrawals from the river as permitted by the SJRWMD. In order to fully understand and predict the potential effects, the SJRWMD released the *St. Johns River Water Supply Impact Study* in February 2012 after a peer review by the National Academy of Sciences — National Resource Council (**SJRWMD 2012b**). In this study, the St. Johns River was divided into segments for analysis – the first three of which fall into the LSJRB:

SEGMENT 1 ("Mill Cove") – extends 39.6 km from Mayport to the Fuller Warren Bridge.
SEGMENT 2 ("Doctor's Lake") – extends 25.4 km from the Fuller Warren Bridge south to a line close to Fleming Island.
SEGMENT 3 ("Deep Creek") – extends 98.1 km from Fleming Island to Little Lake George.

The expected impacts to wetlands in the above segments of the LSJR were analyzed under four different modeling scenarios. One scenario was constructed to create a baseline that was used directly to assess salinity changes. Three scenarios were based on modeled data, a full water withdrawal, and various treatments of land use data, Upper SJRB projects, and sea level rise (**SJRWMD 2012b**). According to the SJRWMD (**SJRWMD 2012b**), the overall results were that "some specific wetland types were reduced in area under each scenario. However, loss in total wetland area was not shown under any scenario with any of the analytical approaches used" (p 10-80, **SJRWMD 2012b**). More specific results of the study are summarized below.

Based on the modeling results, each segment within the LSJRB is expected to experience a change in annual mean salinity, which would, in turn, affect wetland communities. River Segment 1 is predicted to experience a change in mean annual salinity of 0.32 psu, followed by a 0.12 psu change in Segment 2, and 0.011 psu change in Segment 3. The likelihood of salinity effects in Segments 1 and 3 were deemed to be "low," because Segment 1 is already dominated by saltmarsh species which would tolerate the increase in salinity without negative impacts. The increase in salinity in Segment 3 was very small and was not expected to cause noticeable shifts in vegetation. However, river Segment 2 is considered the area of greatest concern, because this area between the Fuller Warren Bridge and the Shands Bridge, is dominated by hardwood swamps and extensive areas of freshwater and transitional vegetation. In this segment, salinity effects were deemed to be "high."

The *St. Johns River Water Supply Impact Study* also evaluated changes in patterns of water inundation and water depth (**SJRWMD 2012b**). However, the segments contained within the LSJRB were not analyzed for change in stage, because water levels in the LSJR are so heavily influenced by sea level. According to this study, the modeled water level change in the Segments 1-4 due to water withdrawals was less than 1 cm. Throughout the entire SJR, the average depth change ranged between 4 cm to less than 2 cm depending on the scenario used. The category of wetlands most negatively impacted throughout the state was "freshwater marshes."

Using the Ortega River as a model system, the *St. Johns River Water Supply Impact Study* examined whether surface water withdrawals could potentially cause movement in the freshwater/saltwater interfaces along the river. SJRWMD researchers identified sampling stations along the Ortega River and conducted vegetation studies. They determined five main wetland plant communities along a gradient from freshwater to brackish water: Hardwood Swamp, Tidal Hardwood Swamp, Lower Tidal Hardwood Swamp, Intermediate Marsh, and Sand Cordgrass Marsh. The soil salinity breakpoints and river salinity breakpoints, where one plant community type shifts to another type, were determined (Table 4.8).

Table 4.8. Soil and River Salinity Breakpoints Causing Wetland Vegetation Shifts in the St. Johns River Basin, Florida (as determined in SJRWMD 2012b).

Soil Salinity Breakpoint	River Salinity Breakpoint	Predicted Distance Moved in St. Johns River
0.47 psu	3.22 psu	2.83 km
1.53 psu	4.13 psu	3.10 km
2.44 psu	4.93 psu	3.30 km
3.41 psu	5.77 psu	3.34 km

The study predicted upstream movement of vegetation boundaries of up to 1.13 km along the Ortega River. When the Ortega River model was applied to the entire St. Johns River, the directional shift of wetland vegetation community types ranged from 3.34 km to less than 0.21 km (**SJRWMD 2012b**).

Thus, certain types of wetland communities will be negatively impacted by future surface water withdrawals in the St. Johns River. These impacts must be considered cumulatively with other expected impacts from future changes in land use, surface water runoff, rainfall, navigational works, groundwater, and sea level rise.

QUESTIONABLE QUALITY. Further investigation is needed to determine the quality and longevity of mitigated wetlands and their ability to actually perform the ecosystem functions of the wetlands they "replace." An increasing proportion of these mitigation wetlands represent uplands/wetlands preserved on average >30 miles from project site (**Brody, et al. 2008**), including many acres in wetland mitigation banks. If preserved wetlands represent already functional wetlands, then they do not replace the ecosystem services lost to development. Currently there is no accounting of the specific locations of each impacted wetland. These wetlands can be depressional wetlands that are not as valued as riverine wetlands (**Brody, et al. 2008**).

Restored and created wetlands generally do not reach ecosystem functioning present in reference wetlands. Based on a meta-analysis from published studies of 621 wetlands, Moreno-Mateos, et al. (**Moreno-Mateos, et al. 2012**) reported that ecosystem services were not returned with restoration efforts in either created or restored wetlands. The size of the wetland (>100 ha) recovered more quickly than smaller wetlands (0.1, 1, and 10 ha). Wetlands only reached on average 74% of biogeochemical functioning **after 100 years**. In addition, plants and vertebrate diversities in restored/created wetlands remained lower than reference wetlands after 100 years. By comparison, macroinvertebrates reached references assemblages between 5 and 10 years. In comparing different types of wetlands, riverine and tidal wetlands recovered more quickly (up to 30 years) as compared to depressional wetlands that did not reach reference conditions (**Moreno-Mateos, et al. 2012**).

Wetlands at the mitigation banks are not necessarily reaching a measure of success relative to reference conditions. Difficulties in restoring wetlands may be related to past activities on the property and indirect effects due to surrounding land use. For example, land use at Loblolly, Tupelo, and Sundew mitigation banks were previously agricultural, managed pasturelands, and mixed agriculture and/or low intensity urban, respectively (**Reiss, et al. 2014**). **Reiss, et al. 2007** investigated success and compliance of 29 wetland mitigation banks in Florida. Barberville, Loblolly, Sundew, and Tupelo were included in their study (Table 4.3 and 4.4). These mitigation banks did not include a target for success criteria or a reference condition (either a reference database and/or comparison sites, **Reiss, et al. 2009**) to measure success (e.g. wildlife needs). With respect to exotic and nuisance cover, final success criteria for state permit requires <10% exotic and nuisance cover (except for Barberville: 5% exotic, 10% nuisance). **Reiss, et al. 2007** recommend that monitoring should also encompass flora and fauna, and not just exotic and nuisance species. At the time of their study, Barberville was a 'long ways off' from final success due to pines having to be replanted. Loblolly and Tupelo had started plantings and was described as not communicating so well in providing the monitoring and management status reports. Sundew was also described as not communicating so well with reports (**Reiss, et al. 2007**). **Reiss, et al. 2007** argue that functional equivalency in wetland mitigation banking remains questionable without a clear method to assess ecosystem function. LDI scores within the mitigation banks indicate that wetland function may be impossible to achieve (**Reiss, et al. 2014**).

The USACE and the EPA have released new rules regarding compensatory mitigation of wetlands impacted by USACE permits (took effect on June 9, 2008). According to the Federal Register, the new rule emphasizes "a watershed approach" and requires "measurable, enforceable ecological performance standards and regular monitoring for all types of compensation" (**USACE 2007**). How these new changes may or may not affect wetland mitigation in the LSJRB warrants future investigation. Given the connectivity of aquifer and ground water via fracture lines, those activities that uptake water in one location may prevent the watershed from being recharged during precipitation events and exacerbate drought effects on wetland systems (**Bernardes, et al. 2014**).

Partial restoration of riparian corridors can have fairly immediate and positive impacts on nutrient levels and diversity of local flora and fauna (**Rossi, et al. 2010**). The authors had planted riparian species of trees, shrubs, grass, and forbs to increase structural complexity in areas 3 x 9.5 m along first-order tributaries of the LSJR. After three months, sampling was conducted for two years. Macroinvertebrate diversity increased (Coleoptera and Lepidoptera), dominance of pollution-tolerant taxa decreased, and pollution-intolerant taxa (Odonta and Ephemeroptera) increased as compared to non-restored sites. In addition, soil nitrate was significantly less in the restoration sites than control sites and soil phosphorous decreased over time in restored sites due to nutrient uptake by the plants. The authors recommend incorporating restoration areas along urban stretches of the river to promote ecosystem function (**Rossi, et al. 2010**).

The Lasalle Bioswale Project showcases another way to minimize contaminants from entering waterways. Bioswales are vegetated areas that collect stormwater runoff. Plants and soil communities take up the pollutants and thereby treat pollutants found in stormwater runoff. This particular project was accomplished by the St Johns Riverkeeper and partners (**St. Johns Riverkeeper 2013b**).

In summary, the future outlook for the health of the LSJRB depends upon detailed, accurate, consolidated record-keeping of wetland impacts, the cumulative impact of parcel-by-parcel loss of wetland ecosystem functions and services, and the success of wetlands enhanced, created, or restored.

4.3. Macroinvertebrates

4.3.1. Description

Benthic macroinvertebrates include invertebrates (animals without a backbone) that live on or in the sediment and can be seen with the naked eye. They include a large variety of organisms such as sponges, crabs, shrimp, clams, oysters, barnacles, insect larvae, and worms. Almost 400 species from 10 phyla have been identified in the LSJRB.

4.3.1.1. Sponges (Phylum Porifera)

Sponges are stationary filter feeding organisms consisting of over 5,000 species with about 150 freshwater species. They do not have organs or tissues, but the cells specialize in different functions. They reproduce both sexually and asexually (**Myers 2001b**). In the LSJRB, five taxa have been recorded and are found in fresh, marine, and estuarine waters (i.e. *Spongilla fragilis* and *Craniella laminaris*) (**Mattson, et al. 2012**).

Sponge. Photo by Kimberly Mann

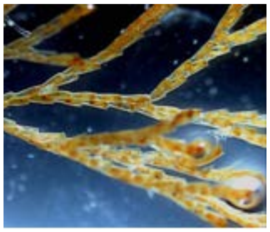
4.3.1.2. Sea Stars and Sea Cucumbers (Phylum Echinodermata)

Brittle Star (Family *Ophioderma)*
Photo by Christina Adams.

Sea Cucumber (*Cucumaria frondosa*)
http://www.sealifebase.fisheries.ubc.ca

There are approximately 7000 marine species. They can range in size from 1 cm to 2 m. Food habits vary among the different species, anything from filter feeders to scavengers to predators. Sea stars can regenerate missing arms, and sea cucumbers and urchins are also able to regenerate certain parts of their anatomy (**Mulcrone 2005**).

4.3.1.3. "Moss Animals" (Phylum Bryozoa)



Genus *Bugula* from http://www.serc.si.edu

This group of animals lives in colonies (**Collins 1999**). They have tentacles which they use to filter phytoplankton out of the water (**Bullivant 1968**). Five non-native species have been recorded in the LSJRB (non-native section, **Mattson, et al. 2012**).

4.3.1.4. Jellyfish, Sea Anemones, and Hydrozoans (Phylum Cnidaria)

All the species in this phylum have stinging cells called nematocysts. They have two basic body forms – medusa and polyp. Medusae are the free-moving, floating organisms such as jellyfish. Polyps are benthic organisms such as the hydrozoans (**Myers 2001c**). In the LSJRB, hydrozoans are more common than jellyfish and sea anemones. Eight taxa have been recorded in the LSJRB, with three taxa found in freshwater including *Corylophora lacustris* (**Mattson, et al. 2012**). The non-native freshwater jellyfish *Craspedacusta sowerbyi* has been recorded in the LSJRB (see non-native section).

Tubularian Hydroid (*Tubularia crocea*)
Photo by Bob Michelson from
http://stellwagen.noaa.gov

Sea Anemone (Order Actiniaria) from
http://digitalmedia.fws.gov

Jellyfish (Class Scyphozoa) from
http://digitalmedia.fws.gov

4.3.1.5. Ribbon Worms (Phylum Nemertea)

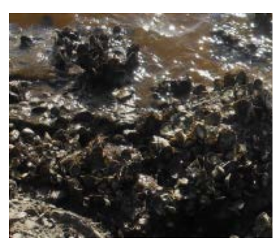
Ribbon Worm (Genus *Tubulanus*)
Photo by Kare Telnes from
http://www.seawater.no/fauna/nemertea/

The common name "ribbon worm" relates to the length of many species with one species being 30 meters. Marine species are more common than freshwater species (**Collins 2001**). Besides long length, these worms have an elongated appendage from the head called a proboscis that they use to capture prey. (**Collins 2001; Graf 2013**). One ribbon worm was recorded by **Evans, et al. 2004** that was salt and pollution tolerant.

4.3.1.6. Snails, Mussels, and Clams (Phylum Mollusca)

The Mollusca are very diverse with >50,000 species, ranging in size from less than a millimeter to more than twenty meters long (giant squids). Over 150 taxa have been identified in the SJRB, including more than 3 invasive taxa (see non-native section) and others endemic to the SJR drainage basin (Elimia sp.) (**Mattson, et al. 2012**). Representative taxa include *Mytilopsis leucophaeata, Gemma gemma, Littoridinops, Boonea impressa, Nassarius obsoletus*, and the non-native *Rangia cuneata* (**Cooksey and Hyland 2007**). Six taxa were recorded by **Evans, et al. 2004** from 2002-2003 collections in the LSJRB. Each taxon was pollution

Snails (Class Gastropoda)
Photo by Kimberly Mann



American oyster (*Crassotrea virginica*)
Photo by Kimberly Mann

Mussel (Class Bivalvia) from
http://digitalmedia.fws.gov

tolerant and two taxa were gastropods and the other four were bivalves.

4.3.1.7. "Peanut Worms" (Phylum Sipuncula)

Peanut Worm (Phylum Sipuncula) from http://www.ucmp.berkeley.edu l

The common name "peanut worm" relates to their shape. Over 320 marine species have been described and they are found in sand, mud, and crevices in rocks and shells (**Collins 2000**).

4.3.1.8. "Horseshoe worm" (Phylum Phoronida)

Genus Phononpsis, Copyright Peter Wirtz peterwirtz2004@yahoo.com l

Approximately 12 marine species have been identified with some species having horseshoe-shaped tentacles (**Collins 1995**). They are most common in shallow sediments. *Phoronis* has been recorded from Clapboard Creek (**Cooksey and Hyland 2007**).

4.3.1.9. Insect larvae (Phylum Arthropoda, Subphylum Crustacea, Class Insecta)

Insect larvae (Class Insecta) from http://digitalmedia.fws.govl

Most insect larval forms look differently from their adult stage. Those larvae associated with aquatic habitats can be found under rocks and in the mud (**Myers 2001a**). Representative genera include *Coelonypus* and *Chrionomus* (**Cooksey and Hyland 2007**). Sixteen taxa were recorded by **Evans, et al. 2004** from 2002-2003 collections in the LSJRB. These taxa were found in freshwater and six were pollution tolerant.

4.3.1.10. Isopods, Amphiphods, and "shrimp-like" crustaceans (Phylum Arthropoda, Subphylum Crustacea, Class Malacostraca, Superorder Peracarida)

It has been estimated that there are over 54,000 species in this group (**Kensley 1998**). They all possess a single pair of appendages (maxillipeds) extending from their chest (thorax) and mandibles. The maxillipeds assist in getting food to their mouth. For this superorder, the carapace (the exoskeleton protecting the head and some to all of the thorax is reduced in size and does not cover all of the thorax. The carapace is also used to brood eggs (**UTAS 2013**). Over 60 taxa have been recorded in the LSJRB (**Mattson, et al. 2012**). In the LSJRB, eleven taxa were recorded of which all were salt-tolerant and four taxa were pollution-intolerant (**Evans, et al. 2004**). Example taxa are *Paracaprella pusilla*, *Apocorophium lacustre*, and *Protohaustroius wigleyi* (**Cooksey and Hyland 2007**). Two species are non-native to the SJRB (see non-native section).

Left: Isopod, photo by A. Slotwinski, from http://www.imas.utas.edu.au
Middle: Amphipod, photo by A. Slotwinski, from http://www.imas.utas.edu.au
Right: Mysid ("shrimp-like"), photo by A. Slotwinski, from http://www.imas.utas.edu.au

4.3.1.11. Crabs and Shrimp (Phylum Arthropoda, Subphylum Crustacea, Class Malacostraca, Order Decapoda)

Blue Crab (*Callinectes sapidus*) from http://digitalmedia.fws.gov

Shrimp (Order Decapoda) Photo by Kimberly Mann

This is one of the most well-known groups since many people eat crabs, shrimps and lobsters. Decapoda refers to the five pairs of legs. This group has an exoskeleton which they periodically have to shed (molt) so they can continue to grow. Their body is divided into three sections – the head, thorax and abdomen. The head and thorax are fused together and covered by the carapace. In crabs, the abdomen is curved under the carapace (**Humann and Deloach 2011**). Approximately 55 taxa of crabs and shrimp have been reported in estuarine, marine, and freshwater in the LSJRB (Appendix 11A). In the SJRB, five species are commercially and/or recreationally (**Mattson, et al. 2012**) harvested. In 2002-3, **Evans, et al. 2004** recorded two taxa in salt waters, of which *Rhithropanopeus harrisii* was pollution intolerant. Four species are non-native to the SJRB (see non-native section).

4.3.1.12. Barnacles (Phylum Arthropoda, Subphylum Crustacea, Class Malacostraca, Infraclass Cirripedia)

Gooseneck Barnacles, http://www.digitalmedia.fws.gov l

There are approximately over 1,400 species. Size can range from a few centimeters to slightly greater than 10 cm. Barnacles are attached to a hard substrate or other organisms. The carapace completely encloses their soft body. They do not possess compound eyes or appendages. For most, their habitat is along rocky shoreline in the intertidal zone (**Newman and Abbott 1980**). Two taxa were recorded by **Evans, et al. 2004** that were salt and pollution tolerant in the LSJRB. Five non-native taxa have been recorded in the LSJRB (see non-native section).

4.3.1.13. Worms (Class Polychaeta, Phylum Annelida)

Limnodrilus hoffmeisteri (Subclass Oligochaeta) from http://www.fcps.edu

Class Polychaete, Photo by Kimberly Mann

This phylum consists of worms that have segmented bodies, including earthworms. Polychaete means "many bristles" and members of this class look like feathered worms. Over 200 taxa have been recorded in the SJRB (**Mattson, et al. 2012**). Example taxa are *Streblospio benedicti*, *Mediomastus*, *Neanthes succinea*, *Nereis*, *Sabellaria vulgaris*, *Paraonis fulgens*, *Nephtys picta* (**Cooksey and Hyland 2007**). *Streblospio benedicti* and *N. succinea* are pollution tolerant and representative of impaired environmental conditions (**Cooksey and Hyland 2007**). Seventeen taxa were recorded by **Evans, et al. 2004**, of which two taxa were pollution intolerant (*Orginiidae* sp. and *Scolopolos rubra*) and another two species that were freshwater tolerant (*Aulodrilus pigueti* and *Limnodrilus hoffmeisteri*) (**Evans, et al. 2004**).

4.3.2. Significance

Benthic macroinvertebrates are an important component of the river's food web. Indeed, many of the adults of these species serve as food for commercially and recreationally important fish and invertebrate species. Their microscopic young can also be very abundant, providing food resources for smaller organisms such as important larval and juvenile fish species. Benthic activities in the sediment or bioturbation can result in sediment turnover, changes in oxygen and nutrient availability, and distribution of grain size. The presence of stress-tolerant species can serve as an indicator of river health (Table 4.3, **Gray, et al. 1979; Pearson and Rosenberg 1978**). For more information on pollution in benthic invertebrates see the contaminants section of this report.

4.3.1. *Data Sources*

Macroinvertebrate community data used to assess long-term trends were obtained from the Florida Department of Environmental Protection (DEP), Florida's Inshore Marine and Assessment Program (IMAP), and the St. Johns River Water Management District (SJRWMD). The primary data set (1973 – 2000) was provided courtesy of the Jacksonville DEP office. Supplemental data from DEP's "Fifth Year Assessments" were obtained online (**DEP 2013d**). Data sets were combined to increase the temporal strength of the analyses. In an attempt to limit bias in community information only data collect via sediment grabs (Ponar, Ekman, and Young modified Van Veen grabs) were used for data up to 2000. Due to the scarceness of data after 2000, data from dipnet sweeps were included from 2001 to present. Differences in the macroinvertebrates were assessed among the three ecological zones based on salinity differences.

4.3.2. *Limitations*

While the dataset encompasses 30 years, similar regions were not sampled throughout the entire time period, different collection methods were used, and sample size was either unequal or insufficient given natural variability. The freshwater lacustrine zone (FLZ) was visited the least with an average of three samples per year. Comparing collections from earlier samples that used mostly petite Ponar grabs with those of more recent collections that used mostly Young modified Van Veen grabs or dipnets is problematic. The dataset includes survey results from deeper sections of the river, because sampling did not occur in shallow areas where boat access was prohibitive.

4.3.3. *Current Status (UNCERTAIN)*

Evidence of shifts from low-salinity, pollution-sensitive taxa to higher-salinity, pollution-tolerant taxa at a site where Sisters Creek meets Ft. George River (**Hymel 2009**). **Evans, et al. 2004** reported occurrences of larval deformity from 20 sites in the LSJRB. Severely to very severely impaired sites (75-100% pollution tolerant taxa and larval deformities of 0->9) were identified for Cedar River, Little Fish Weir, Ortega River, Julington Creek, Ribault River, Moncrief Creek, Goodby's Creek, and Trout River (Table 4.3). Deformities of *Chironomus* and *Coelotanypus* larvae can be due to metals such as lead and copper, organic compounds. Impairment of these sites may be due to low dissolved oxygen, toxic compounds, nutrient loading, and/or poor quality of sediment (**Evans, et al. 2004; Hymel 2009**).

Table 4.3. Percentage of pollution and salt tolerant invertebrates and numbers of deformities in the LSJR (from Evans, et al. 2004).

SITE LOCATION	% POLLUTION TOLERANT TAXA 2001, 2002/3	% SALT TOLERANT	OCCURRENCE OF DEFORMITIES 2002/3 (# of deformities)	# TAXA AND DENSITY OF INDIVIDUALS
Arlington River	100			
Cedar Creek	81			
Green Cove Springs	74, 76	33	*Coelotanypus* 0 (0)	6 taxa 356 individuals/m^2
Rice Creek	14-86			
Julington Creek	100, 93	48	*Coelotanypus* 100 (12)	7 taxa present 453 individuals/m^2
Ortega River	77-100			
Goodby's Creek	97-99, 34	6	*Coelotanypus* 1004 (4)	10 taxa present 346 individuals/m^2
Cedar River	**99-100**			
Trout River	100, 96	80	*Polypedilum halterale griseopunctatum* 0 (1)	6 taxa present 269 individuals/m^2
Doctor's Lake	-, 100	100	Absent	1 taxon present 356 individuals/m^2
Clapboard Creek	-, 82	100	Absent	15 taxa present 896 individuals/m^2

Benthic macroinvertebrate assemblages change from the saltwater dominated mesohaline riverine zone (MRZ) to the freshwater areas of the freshwater lacustrine zone (FLZ) (**Mason Jr 1998**, **Cooksey and Hyland 2007**, **Evans and Higman**

2001, **Evans, et al. 2004**, and **Vittor 2001; Vittor 2003**; Figure 4.8; For a complete list of species see Appendix 4.3.6). As stated in section 2.8, the mesohaline riverine zone is 40 km long running from Mayport Inlet to the Fuller Warren Bridge with an average salinity of 14.5 psu. The oligohaline lacustrine zone (OLZ) has an average salinity of 2.9 psu and encompasses the area from the Fuller Warren Bridge, 35 miles along the river to Doctors Lake. The two northern zones were dominated by annelids, the MRZ by polychaetes, and the OLZ by oligochaetes (Table 4.4). In addition, the MRZ had a high percentage of amphipods and isopods, the OLZ with molluscs, and the FLZ with insect larvae. In the 1970's the MRZ was dominated by barnacles and the amphipod group, the OLZ by mussels, and the FLZ by insect larvae (Figure 4.8). In the 1990's, polychaetes were abundant as compared to barnacles in the MRZ, isopods were more abundant in the OLZ, and mussels were more abundant in the FLZ (Figure 4.8).

4.3.4. Trend (UNCERTAIN)

Community shifts are expected in response to the natural changes in water quality, salinity, and temperature in addition to biological factors that can include recruitment and predation variability (**Cooksey and Hyland 2007**). It is important to recognize that the mechanism by which many of these organisms may be affected is by either direct impact to adults or to the offspring that spend part of their time in the water column as plankton. During the planktonic stage of these organisms, environmental gradients (i.e. salinity, temperature, dissolved oxygen) within the river can affect where young are and how they are transported to another habitat.

The lack of recent surveys and monitoring of benthic macroinvertebrates makes it difficult to identify trends, especially since microhabitat variability can be as high as site variability. Yet, low species richness, diversity, and abundance are representative of impaired benthic conditions (**Cooksey and Hyland 2007**). The health of the SJR is linked to the health of benthic macroinvertebrates. A concern is if macroinvertebrate communities change in a large area within the river, and then affect abundances of ecologically, commercially or recreationally important species (for example red drum, spotted sea trout, or flounder).

Table 4.4. Common macroinvertebrate taxa in LSJR

SEGMENT	DOMINANT TAXA	REPRESENTATIVE TAXA	SOURCES
Tidal freshwater/upper oligohaline	Freshwater Oligochaete Mollusc Aquatic insect	Isopod *Cyathura polita* Mysid *Mysidopsis almyra* Aquatic insect *Chironomus plumosus*, *C. decorus*, *Glyptotendipes lobiferus, Callibaetis floridanus, Stenacron floridense, Oecetis, Hydroptila, Orthotrichia, Cyrnellus fraternus, Lype diversa*	**Cichra 1998; Mason Jr 1998**
Lower oligohaline/upper mesohaline	Estuarine Polychaete Amphipod Mysid Decapod Mollusk Aquatic insect	Polychaete *Streblospio bendicti*, *Marenzelleria viridis, Limnodrilus hoffmeisteri, Questridilus multisetosus* Amphipod *Corophium*, *Hartmanodes nyei, Gammarus* Decapod *R. leucophaeata*, Snail *Littoridinops monroensis* Bivalve *Corbicula fluminea, Rangia cuneata, Mytilopsis leucophaeata, Ischaedium recurvum, Macoma mitchelli* Gastropod *Physa*, *Amnicola*, *Littoridinops* Barnacle *Ischadium recurvum* Aquatic insect *Coelotanypus*, *Chironomus plumosus*, *Glyptotendipes lobiferus*	**Cichra 1998; Cooksey and Hyland 2007; Mason Jr 1998**
Lower mesohaline/polyhaline	Estuarine, marine Mollusc Polychaete Oligochaete Amphipod Crustacean Echinoderm	Bivalve *Tellina*, *Macoma tenta, Mytilopsis leucophaeta, Ischadium recurvum, Mulinia lateralis, Boonea impressa, Gemma gemma* Polychaete *Capitella capitata*, *Mediomastus californiensis*, *S. benedictii, Neanthes succinea, Nereis, Sabellaria vulgaris, Paranois fulgens, Nephtys picta* Amphipod *Protohaustroius wigleyi* Oligochaete *Tubificoides heterochaetus,* Crustacean *Apocorphium lacustre*	**Banks 2015; Cooksey and Hyland 2007**

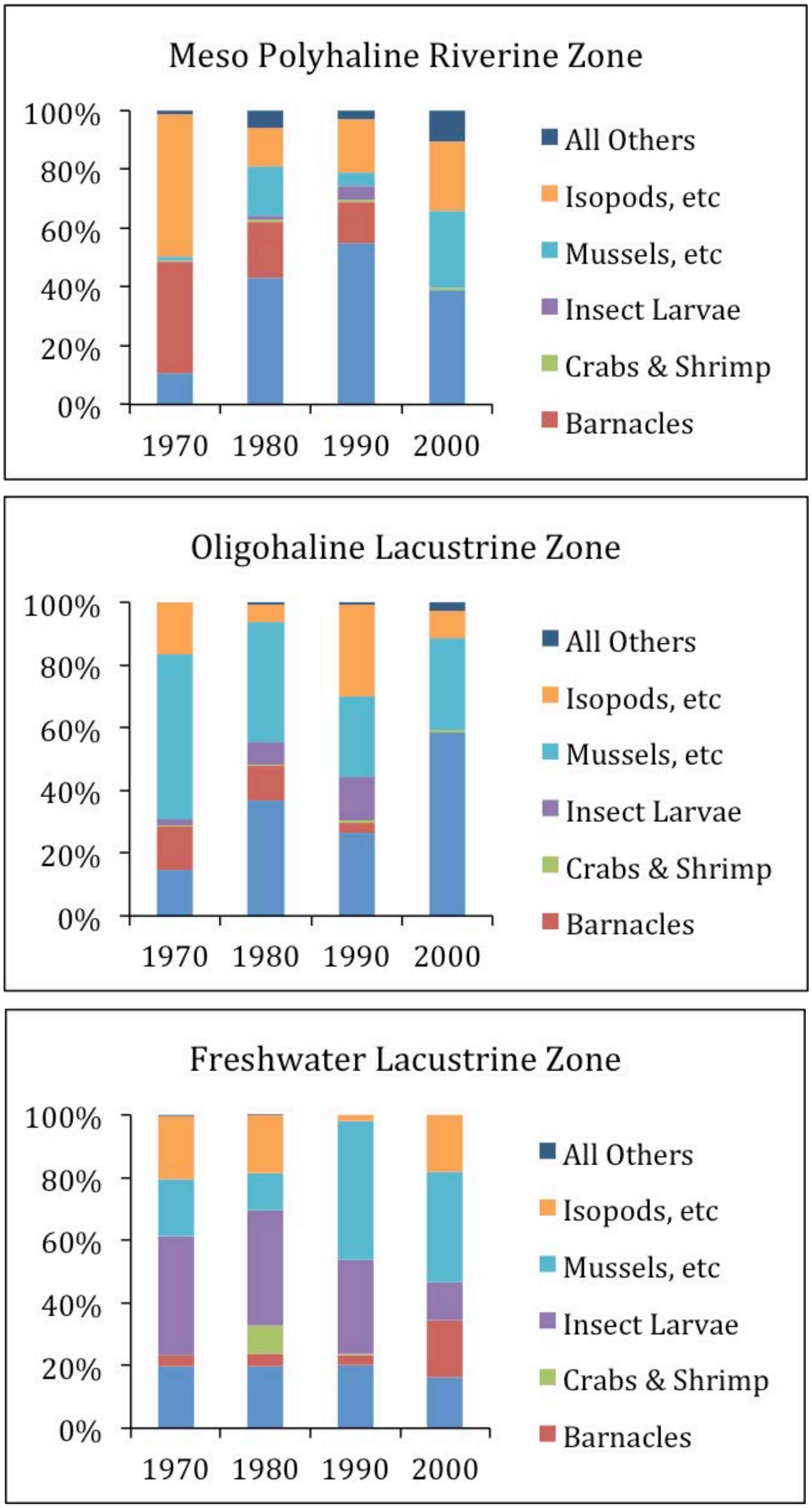


Figure 4.8: Percent of macroinvertebrate present each decade in the three ecological zones of the Lower Basin of the St. Johns River from the 1970's to 2000. The meso-polyhaline riverine zone is dominated by barnacles, polychaete worms, and isopods/amphipods. Insect larva and oligochaete worms dominate the freshwater lacustrine zone with mussels gaining influence in the 1990's and 2000's. The oligohaline lacustrine zone reflects its transition between salinity and freshwater by being dominated by mussels and worms, both polychaetes and oligochaete.(***Mason Jr 1998****,* ***Cooksey and Hyland 2007****,* ***Evans and Higman 2001****,* ***Evans, et al. 2004****, and* ***Vittor 2001; Vittor 2003****).*

4.4. Threatened & Endangered Species

The species examined in this section are Federally-listed threatened and endangered species that occur in Duval, Clay, St. Johns, Putnam, Flagler and Volusia Counties in the LSJRB (**USFWS 2014a**). These animals are protected under the Endangered Species Act of 1973 (**Congress 1973**). The West Indian manatee, bald eagle and wood stork are considered primary indicators of ecosystem health because of their direct use of the St. Johns River ecosystem. The data available for these species were relatively more robust than data on the also listed shortnose sturgeon, piping plover, Florida scrub-jay, and Eastern indigo snake. In addition, other endangered or threatened species of interest to the area include the North Atlantic Right Whale and Loggerhead Sea Turtle. However, because these animals are associated with the coastal and offshore boundaries of the LSJRB, they are not discussed in this report. All these examples convey in part the diverse nature of endangered wildlife affected by human activities in the LSJRB. These species, and many more, add to the overall diversity and quality of life we enjoy and strive to protect and conserve for the future. It is important to be aware that human actions within the LSJRB affect the health of the entire ecosystem, and that the St. Johns River is a critical component of this system. Research, education and public awareness are key steps to understanding the implications of our actions towards the environment. The list of species examined here does not include all species protected under Florida State (133 species within the state) and federal laws (15 species within LSJRB) (see Appendix 4.4.1). It is likely that in the future this list will need to be periodically updated as changes occur over time or indicator species and data are identified. For additional supporting information the reader is asked to refer to the appendices section of the report.

4.4.1. The Florida Manatee (Endangered)

Source: G Pinto

4.4.1.1. Description

In 1967, under a law that preceded the Endangered Species Act of 1973 the manatee was listed as an endangered species (**Udall 1967**). Manatees are also protected at the Federal level under the Marine Mammal Protection Act of 1972 (**Congress 1972b**), and by the State under the Florida Manatee Sanctuary Act of 1978 (**FWC 1978**).

The Florida manatee (*Trichechus manatus latirostris*) is a large aquatic mammal that inhabits the waters of the St. Johns River year round and may reach a length of 12 feet and a weight of 3,000 lbs. (**Udall 1967**; **USFWS 2001**). They are generally gray to dark-brown in color; have a seal-like body tapering to a flat, paddle-shaped tail. Two small forelimbs on the upper body have three to four nails on each end. The head is wrinkled and the face has large prehensile lips with stiff whiskers surrounding the nasal cavity flaps. They are not often observed during winter (December-February) being generally most abundant in the St. Johns River from late April through August. Because of their herbivorous nature all are found in relatively shallow waters where sunlight can penetrate and stimulate plant growth. Manatees do not form permanent pair bonds. During breeding, a single female, or cow, will be followed by a group of a dozen or more males, or bulls, forming a mating group. Manatees appear to breed at random during this time. Although breeding and birth may occur at any time during the year, there appears to be a slight spring calving peak. Manatees usually bear one calf, although twins have been recorded. Intervals between births range from three to five years (**JU 2015**). In 1989, Florida's Governor and Cabinet identified 13 “key” counties experiencing excessive watercraft-related mortality of manatees and mandated that these counties develop a Manatee Protection Plan (MPP). The following counties have state-approved

MPPs: Brevard, Broward, Citrus, Collier, Dade, Duval, Indian River, Lee, Martin, Palm Beach, Sarasota, St. Lucie, and Volusia (**FWC 2014c**). In 2006, although not one of the original 13 "key" counties, Clay County also voluntarily developed a State-approved MPP. St. Johns County also voluntarily developed a manatee plan, but it is has not been approved by State or Federal agencies. Putnam County does not have a MPP, whereas Flagler County is in the process of developing one. The Duval MPP was last revised in 2014.

Jacksonville University has conducted some 727 aerial surveys with over 16,990 manatee sightings (1994–2014). These year–round surveys covered the shorelines of the St. Johns River, its tributaries (Jacksonville to Black Creek), and the Atlantic Intracoastal Waterway (Nassau Sound to Palm Valley). During the winter, industrial warm water sources were also monitored for manatee presence (aerial and ground surveys). It was observed that when water temperatures decrease (December through March); the majority of manatees in the LSJRB migrate to warmer South Florida waters (**White and Pinto 2014**).

Within the St. Johns River, survey data indicate that manatees feed, rest and mate in greater numbers south of the Fuller Warren Bridge where their food supply is greatest relative to other areas in Duval County. Sightings in remaining waters have consisted mostly of manatees traveling or resting. Manatees appear to use the Intracoastal Waterway as a travel corridor during their seasonal (north/south) migrations along the east coast of Florida. Data indicate that manatees stay close to the shore, utilizing small tributaries for feeding when in these waters (**White, et al. 2002**). Aerial surveys of manatees, by various organizations and individuals, in northeast Florida have occurred prior to 1994 and are listed in **Ackerman 1995**.

There are two sub-populations of manatees that use the LSJRB. The first sub-population consists of about 400 manatees from the Blue Springs area (**Hartley 2015**), of which numbers visiting the LSJRB are not known (**Ross 2015**). Most of the animals in the LSJRB (about 260 manatees) (**White and Pinto 2006a**; **White and Pinto 2006b**) are members of the greater Atlantic region sub-population, with 2,432 animals in 2011 along the entire east coast of Florida (**FWRI 2015c**). A State synoptic survey was not conducted in 2012 or 2013, because weather conditions were not preferable. The warm winters meant that manatees did not aggregate well at warm water sources for counting. In 2011, 21 observers from 10 organizations counted 2,438 manatees on Florida's east coast and 2,402 on the west coast for a sum total of 4,840. No animals were observed in the northeast synoptic survey area in 2011. In 2014, 2,315 animals were observed on the east coast; 2,509 on the west coast of Florida for a total of 4,824 animals. Only two animals were observed in the northeast synoptic survey area. Preliminary data in 2015 indicated that a new record number of manatees was observed with 3,333 animals on the east coast, and 2,730 on the west coast of Florida, for a total of 6,063 manatees (no animals were observed in the northeast synoptic survey area (**FWRI 2015a**). The weather conditions in 2010 were the coldest for the longest duration in Florida metrological history. Consequently, manatees were more concentrated at warm water sources throughout the state resulting in the second highest count ever recorded with 2,780 animals on the east coast, and 2,296 animals on the west coast for a sum total of 5,076 animals. From all these, two animals were observed in the northeast synoptic survey area in 2010. The previous high count in 2009 was 2,148 animals on the east coast, and 1,654 animals on the west coast for a total of 3,802 animals (**FWRI 2015a**). It should be noted that because of differences in the ability to conduct accurate aerial surveys the synoptic results cannot be used to assess population trends. For more information see Appendix 4.4.1.A_Synoptic Counts. This information is based on the results of long-term radio tracking and photo-identification studies (**Beck and Reid 1998**; **Reid, et al. 1995**). **Deutsch, et al. 2003** reported that the LSJR south of Jacksonville was an important area visited by 18 tagged manatees that were part of a 12-year study of 78 radio-tagged and tracked manatees from 1986 to 1998. Satellite telemetry data support the fact that most animals come into the LSJRB as a result of south Florida east coast animals migrating north/south each year (**Deutsch, et al. 2000**). Scar pattern identification suggests that significant numbers of manatees are part of the Atlantic sub-population. Only three manatee carcasses (1988, 1989, and 1991) have been recovered in the Jacksonville area, and another three between the Buckman Bridge and Palatka (1989, 1997, and 2003) that have been identified as animals that came from the Blue Springs sub-population (**Beck 2015**).

*"Synoptic" can be defined as a general Statewide view of the number of manatees in Florida. The FWC uses these surveys to obtain a general count of manatees statewide by coordinating an interagency team that conducts the synoptic surveys from one to three times each year (weather permitting). The synoptic surveys are conducted in winter and cover all of the known wintering habitats of manatees in Florida. The survey is conducted to meet Florida state statute 370.12 (4), which requires an annual, impartial, scientific benchmark census of the manatee population. From 1991 through 2015, the counts have been conducted 29 times (**FWRI 2015a**).*

4.4.1.2. Significance

The St. Johns River provides habitat for the manatee along with supporting tremendous recreational and industrial vessel usage that threatens them. From 2000 to 2014, pleasure boats have increased the most and represent about 97% of all vessels. St. Johns and Clay Counties experienced an increasing trend in the number of vessels. Duval and Putnam Counties experienced a decreasing trend in vessels. For information about each county see Appendix 4.4.1.A Vessel Statistics. Watercraft deaths of manatees continue to be the most significant threat to survival. Boat traffic in the river is diverse and includes port facilities for large industrial and commercial shippers, commercial fishing, sport fishing and recreational activity. Florida Department of Highway Safety and Motor Vehicles (**FDHSMV 2015**) records show that there were 34,483 registered boaters in Duval County in 2002. This number increased to 34,494 by 2007, and has since fallen from 28,519 in 2012 to 27,203 in 2014. Duval County had the most vessels (46%) followed by St. Johns and Clay (18%) then Putnam (12%) and Flagler (7%). Port statistics indicated that as many as 4,166 vessel passages occurred to and from the Port in 2012, and that these decreased to 3,692 in 2014 year (**JAXPORT 2015**). In addition to this, in 2004, there were 100 cruise ship passages to and from the Port, and by 2007, this number rose to 156. In 2008 there was a decrease to 92 cruise ship passages, and then from 2009-2014 the number of passages averaged 155. Large commercial vessel calls and departures are projected to increase significantly in the future (**JAXPORT 2007**). Also, in order to accommodate larger ships, the JAXPORT dredged turning basins in 2008 and plans to deepen the channel in 2014/2015. Dredging can cause a change in vessel traffic patterns and increase noise in the aquatic environment that can potentially harm manatees because they cannot hear oncoming vessels (**Gerstein, et al. 2006**). Dredging a deeper channel can also affect the salinity conditions in the estuary by causing the salt water wedge to move further upstream (**Sucsy 2008**), which may negatively impact biological communities like tape grass beds on which manatees rely for food (**Twilley and Barko 1990**).

4.4.1.3. Data Sources & Limitations

Aerial survey data collected by Jacksonville University (Duval County 1994-2014, and Clay County 2002-2003) were used in addition to historic surveys by FWC (Putnam 1994-1995). Ground survey data came from Blue Springs State Park (1970-2014). The FWRI provided manatee mortality data from 1975-2014. Other data sources include the USGS Sirenia Project's radio and satellite tracking program, manatee photo identification catalogue, tracking work by Wildlife Trust and various books, periodicals, reports and web sites.

Aerial survey counts of manatees are considered to be conservative measures of abundance. They are conducted by slow-speed flying in a Cessna high-wing aircraft at altitudes of 700-1,000 ft. (**JU 2015**) and visually counting observable manatees. The survey path was the same for each survey and followed the shorelines of the St. Johns River and tributaries, about every two weeks. Throughout the year, survey time varied according to how many manatees were observed. This is because more circling is often required to adequately count them. The quality of a survey is hampered by a number of factors including weather conditions, the dark nature of the water, the sun's glare off the water surface, the water's surface condition, and observer bias. The units of aerial surveys presented here are the average number of manatees observed and the single highest day count of manatees per survey each year. The number of surveys each year averaged 19 ± 3.5 SD (range 11-26/yr.) Funding for aerial surveys was significantly reduced in the period from 2012-2015, due to budget cuts, which resulted in a lower survey frequency of 3-5 surveys/yr. This significantly reduced the power to predict trends and represents a further limitation in the data.

The actual location that a watercraft-related mortality occurred can be difficult to determine because animals are transported by currents or injured animals continue to drift or swim for some time before being reported. In addition, the size of the vessel involved in a watercraft fatality is often difficult to determine with frequency and consistency.

Because the frequency and duration of elevated salinity events in the river can adversely affect the health of Submerged Aquatic Vegetation (SAV) on which manatee rely for food, rainfall and salinity were examined in conjunction with the number of manatees. Salinity data were provided by Betsy Deuerling (Environmental Quality Division, City of Jacksonville). Water quality parameters are measured monthly at ten stations in the main stem of the St. Johns River at the bottom (5.0 m), middle (3.0 m), and surface (0.5 m) depths. Data on rainfall came from the SJRWMD and NOAA (Appendix: 4.1.7.1.E. Rainfall, Hurricanes, and El Nino), and salinity data for specific SAV monitoring sites came from SJRWMD (Appendix: 4.1.7.1.F. Salinity). Regarding the salinity data associated with SAV sites and including grass beds information, these data were not available for 2012 because those programs were suspended due to budget cuts.

4.4.1.4. Current Status

Aerial surveys: The average numbers of manatees observed on aerial surveys in Duval County and adjacent waters decreased prior to the drought (2000-2001) and then increased again after the drought (2000-2005). In 2005, drought conditions developed again and numbers began to decline (Figure 4.10). Since 2009, manatee numbers have begun to increase again. The longer-term trend (1994-2014) appears to be relatively stable, when excluding the variation caused by the droughts. Data points from 2013 to 2014 are likely to be significantly affected by reduced sampling frequency.

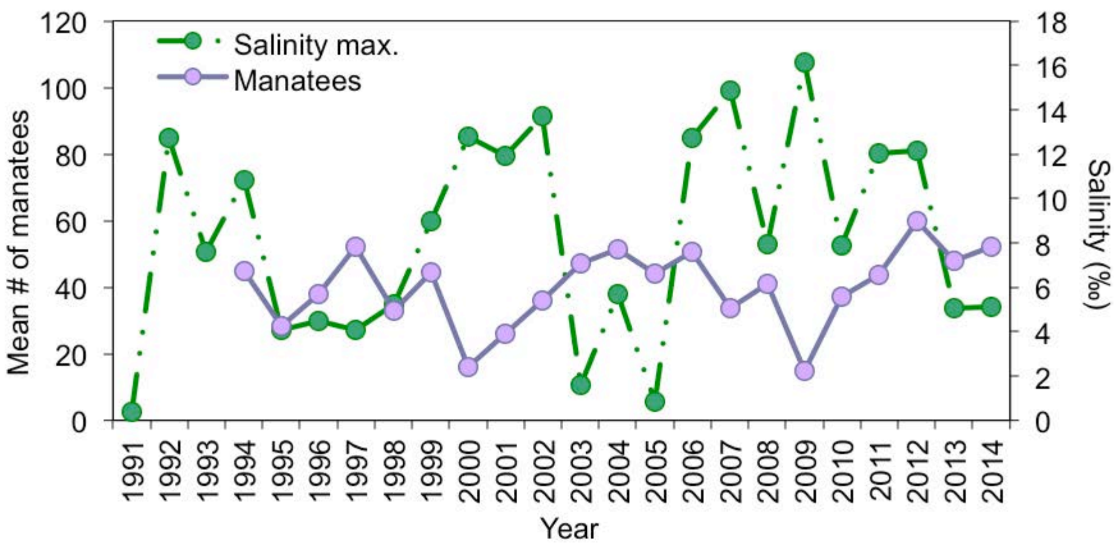


Figure 4.10. Mean numbers of manatees per survey in Duval Co., FL and adjacent waters 1994-2014. Data source: Jacksonville University and City of Jacksonville (Appendix 4.4.1.A).

Single highest day counts of manatees appear to have increased to a level slightly higher than prior to the drought, but the increase is not statistically significant (2000-2005). The large dip in numbers in 1999-2000 can be attributed to the effects of the drought that caused manatees to move further south out of the Duval County survey area in search of food (Figure 4.11). A second dip in numbers (2005-2009) occurred as a result of another series of droughts. In 2010, manatee numbers began to increase again and in 2012 the highest count (177 manatees) to date was recorded. Data points from 2013 to 2014 are likely to be significantly affected by reduced sampling frequency.

"Single highest day count" of manatees is defined as the record highest total number of manatees observed on a single aerial survey day during the year. This provides a conservative indication of the maximum number of manatees in the study area.

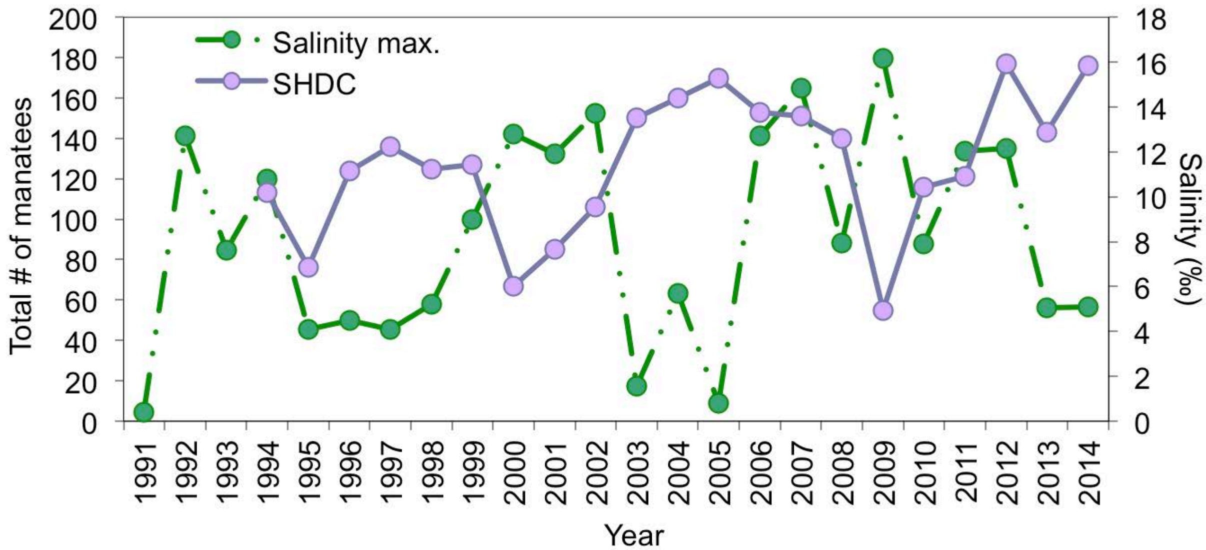


Figure 4.11. Single highest day count per year of manatees in Duval Co., FL 1994-2014. Data source: Jacksonville University and City of Jacksonville (Appendix 4.4.1.A).

Ground surveys: Blue Springs is located about 40 miles south of the LSJRB within the St. Johns River system and, since this sub-population has increased over the years, we could potentially see more animals using the LSJRB in the future. The population of Blue Springs only numbered about 35 animals in 1982-83 (**Kinnaird 1983a**) and 88 animals in 1993-94 (**Ackerman 1995**). From 1990-1999, this population had an annual growth rate of about 6% (**Runge, et al. 2004**). It is the fastest growing sub-population and accounts for about 5% of the total Florida manatee count (**FWC 2007**). Ground surveys indicate that the six year average for total number of manatees seen has increased from 6% (1994-2003) to 22% (2004-2014); note also that most of these animals stay in the vicinity of Blue Springs (Figure 4.12).

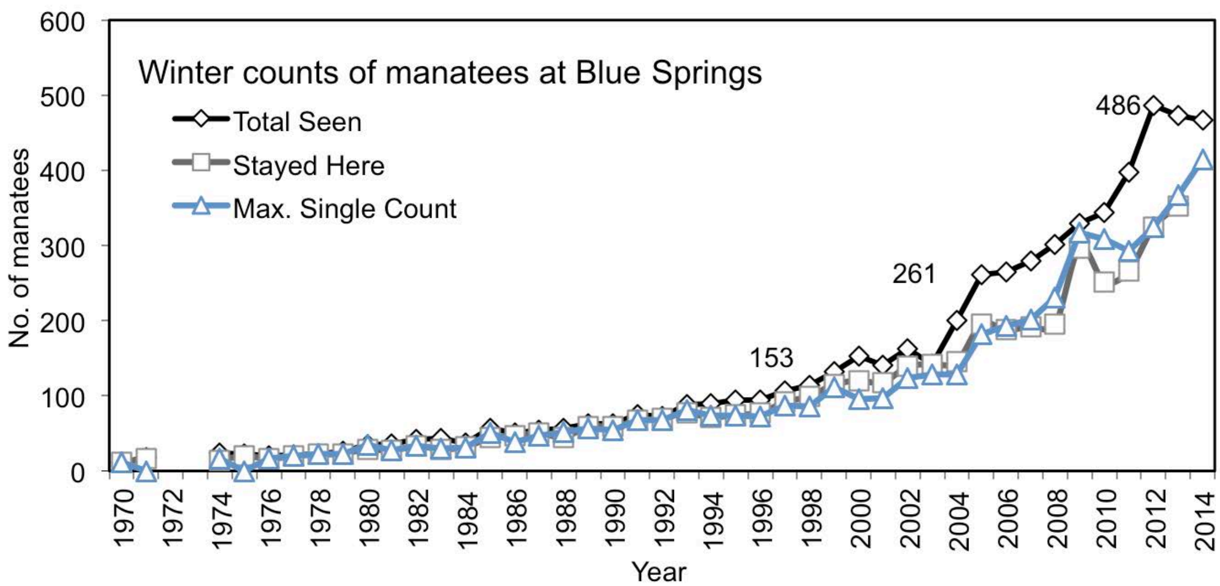


Figure 4.12. Winter counts of Florida manatees identified at the winter aggregation site in Blue Springs State Park, Volusia Co., FL 1970-2014. Maximum single day counts and animals that stayed at the site are also indicated. Data source: ***Hartley 2015****.*

Total Mortality: There were a total of 644 manatee deaths in the LSJRB from 1981-2014 (Fig. 4.13), of which a total of 183 were caused by watercraft (28% of total manatee deaths), 11 were from other human related causes, 120 were of a perinatal nature, 120 were from cold stress, 37 from other natural causes and 169 were from undetermined causes. The total number of manatee mortalities (from all causes) increased towards the mouth of the SJR with Duval County being associated with 60% of all deaths, followed by Clay (12%) and Putnam (11%), then St. Johns (10%), and finally Flagler County with 7% (**FWRI 2015a**). There were no deaths in Flagler during 2011, five in 2012, four in 2013, and six in 2014.

Manatee mortality categories defined by FWRI

Watercraft (Propeller, Impact, Both)	*Cold Stress*
Flood Gate/Canal Lock	*Natural, Other (Includes Red Tide)*
Human, Other	*Verified; Not Recovered*
Perinatal (Natural or Undetermined)	*Undetermined; Too decomposed*

Watercraft Mortality: Watercraft-related mortalities in 2014, as a percentage of the total mortality by-county, were highest in Duval (35%) followed by Putnam (21%), Clay (19%), and St. Johns had about 17%, and Flagler less than 0.2%. Over the past few years, an unusually high number of watercraft related manatee deaths in Duval County resulted from encounters with large, probably commercial, vessels. Since most deaths in the basin occurred in Duval County, watercraft deaths in Duval County were compared in five-year increments beginning 1980 thru 2014. These time periods were picked because they represent uniform time periods either side of 1994 when the Interim Duval County MPP regulations were implemented. From 1980 to 2004, watercraft deaths of manatees in Duval County averaged 31% of total deaths and from 2005 to 2010, watercraft deaths were 52% of total deaths. In the last five years (2010 to 2014), watercraft-caused mortality decreased to 24% of total manatee mortalities (Appendix 4.4.1.A). In comparison to the Duval rate, the average watercraft death rate for the state was significantly lower for the same time period 16% (11% of total mortalities in 2010; 19% (2011); 21% (2012); 9% (2013), and 18% (2014). Mortalities from watercraft in LSJRB show an upward trend since the mid-1990s, with most reported in Duval County. The watercraft mortality for the LSJRB was 34% of total mortality in 2009, and the state watercraft mortality rate was 23%. In 2008, it was 33% in the LSJRB compared to 27% for the State; in 2007, 32% (LSJRB) versus 23% for the state (**FWC 2014e**).

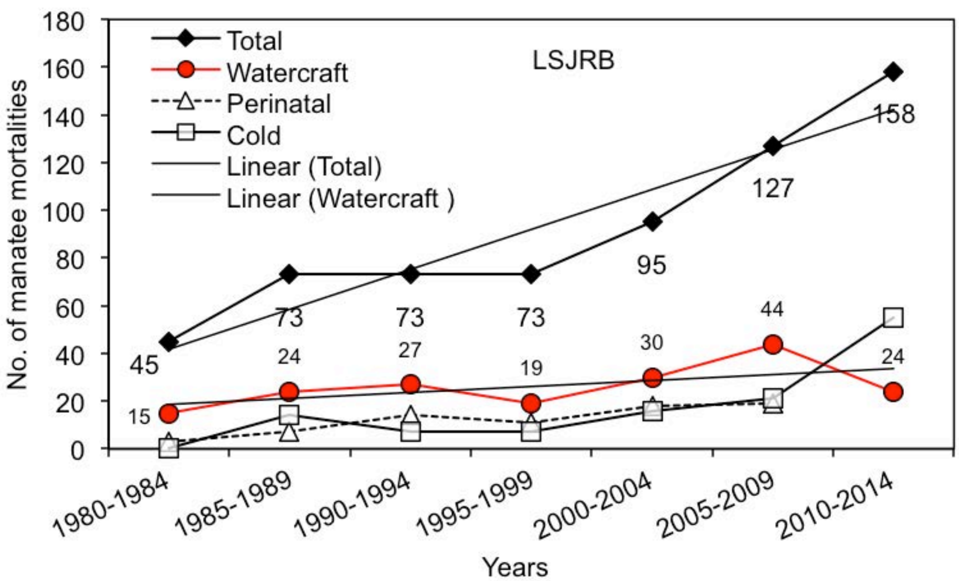


Figure 4.13. Summary of total, watercraft, perinatal, and cold stress manatee mortalities by county in LSJRB (five-year intervals from 1980-2014).

Cold stress: When manatees experience prolonged exposure to water temperatures below 68°F (20°C), they can develop a condition called cold-stress syndrome, which can be fatal. Effects of cold stress may be acute, when manatees succumb rapidly to hypothermia, or longer-lasting as chronic debilitation. Chronic cold-stress syndrome is a complex disease process that involves metabolic, nutritional, and immunologic factors. Symptoms may include emaciation, skin lesions or abscesses, fat depletion, dehydration, constipation and other gastrointestinal disorders, internal abscesses, and secondary infections.

Cold-stress mortalities were particularly elevated throughout Florida during the period January to March 2010. This time frame included the coldest 12-day period ever recorded in the state of Florida with temperatures below 45°F (7.2°C) recorded in Naples and West Palm Beach. Central Florida experienced even colder temperatures. From January-April, 58 manatees were rescued and 503 manatee carcasses were verified in Florida (429 in all of 2009). Mortality was highest in the central-east and southwest regions. Florida manatees rely on warm-water refuges to survive winter and extended cold periods which are of particular concern because the long-term survival of these animals will be dependent on access to warm water springs as power plant outfalls throughout the Florida peninsula are shut down (**Laist, et al. 2013**). In LSJRB there were a total of 12 cold stress deaths between January 14th and February 15th 2010 – Clay (2), Duval (1), Flagler (0), Putnam (7), and St. Johns (2), compared to a total of 6 cold stress deaths in 2011 – Clay (0), Duval (3), Flagler (0), Putnam (2), and St. Johns (1). (**FWRI 2012b**).

The State Manatee Management Plan (**FWC 2007**) requires the FWC to evaluate the effectiveness of speed zone regulations. The Plan was developed as a requirement in the process, which seeks to down list manatees from endangered to threatened status. Currently, manatees are considered endangered at both the state and federal level. Taking everything into account, the current STATUS of the Florida Manatee is *satisfactory*, and the TREND is *unchanged.*

4.4.1.5. Future Outlook

Manatees in the LSJRB are likely to continue to increase as more manatees move north because of decreases in manatee habitat and its quality in south Florida. Recovery from the most recent drought cycle (2009-2012) should allow food resources to rebound and increase the carrying capacity of the environment to support more manatees. Current information regarding the status of the Florida manatee suggests that the population is growing in most areas of the southeastern U.S. (**USFWS 2007d**). In 2013, the aerial survey budget was significantly reduced to the point that useful information about population trends is more limited. In light of that issue, the USCG Auxiliary Air Unit stepped up to offer assistance in providing flights, when possible. Just like in Lee County, Florida (**Semeyn, et al. 2011**) the manatee count and distribution information in the form of maps is discriminated to local, state and federal law enforcement, maritime industry groups, the port, and the media so that efforts can be focused on raising public awareness through education. The focus on education is primarily so that manatee deaths from watercraft can be reduced. In early 2013, the area experienced significant rainfall, the effects of which have yet to play out. Moreover, some algae blooms in the mains stem of SJR near Doctors Lake were observed from the air during manatee aerial surveys in late May of 2013 that were provided by USCG Auxiliary Air Group. There has been a spatial shift over the last decade in that fewer manatees are seen in areas north of the Buckman Bridge, and more tend to congregate further south. This correlates with more suitable habitat to the south verses the north. The trend in watercraft-caused deaths continues to increase over time (**FWRI 2015c**). Significant increases in vessel traffic in the LSJRB are projected to occur over the next decade as human population increases and commercial traffic doubles. More boats and more manatees could lead to more manatee deaths from watercraft because of an increased opportunity for encounters between the two. Dredging, in order to accommodate larger ships, significantly affects boat traffic patterns and noise in the aquatic environment (**Gerstein, et al. 2006**) and has ecological effects on the environment that ultimately impact manatees and their habitat. Freshwater withdrawals, in addition to harbor deepening, will alter salinity regimes in the LSJRB; however, it is not known yet by how much. If a sufficient change in salinity regimes occurs, it is likely to cause a die-off of the grass bed food resources for the manatee. This result would decrease carrying capacity of the environment's ability to support manatees. Some Blue Springs animals use LSJRB too, although the interchange rate is not established yet. Animals that transition through the basin are likely to be affected by the above issues. Sea level rise is another factor likely to affect the St. Johns and about which more information regarding potential impacts is needed. In addition, any repositioning of point sources can alter pollution loading to the St. Johns River and should be monitored for any potential impacts to manatees (i.e. thermal/freshwater sources), and also the grass beds on which they depend for food. Moreover, the cumulative effects of freshwater withdrawals on these and other flora and fauna should be monitored to assess the impacts of water supply policy (**NRC 2011**). Important monitoring programs have been reduced or eliminated due to budget cuts in the last few years. Fewer data impacts the ability of planners to gauge the effectiveness of programs that have the goal of improving environmental conditions in the river and may lead to additional costs in the future.

"Carrying Capacity" may be defined as the maximum weight of organisms and plants an environment can support at a given time and locality. The carrying capacity of an environment is not fixed and can alter when seasons, food supply, or other factors change.

4.4.2. Bald Eagle (delisted 2007)

Photo: Dave Menken, USFWS.

4.4.2.1. Description

The bald eagle *(Haliaeetus leucocephalus)* is a large raptor with a wingspan of about seven feet and represents a major recovery success story. Bald eagles were listed as endangered in most of the U.S. from 1967-1995 as a result of DDT pesticide contamination, which was determined to be responsible for causing their eggshells to be fragile and break prematurely. The use of DDT throughout the U.S. was subsequently banned, though it is still present in the environment (See Section 5.6 Pesticides). In 1995 bald eagle status was upgraded to threatened and numbers of nesting pairs had increased from just under 500 (1960) to over 10,000 (2007).

As a result of this tremendous recovery, bald eagles were delisted June 28, 2007 (**AEF 2014; USFWS 2007e; USFWS 2008d; USFWS 2008c**). The eagles are found near large bodies of open water such as the St. Johns River, tributaries, and lakes, which provide food resources like fish. Nesting and roosting occurs at the tops of the highest trees (**Jacksonville Zoo 2014; Scott 2003a**). Bald eagles are found in all of the United States, except Hawaii. Eagles from the northern United States and Canada migrate south to over winter while some southern bald eagles migrate slightly north for a few months to avoid excessive summer heat (**AEF 2014**). Wild eagles feed on fish predominantly, but also eat birds, snakes, carrion, ducks, coots, muskrats, turtles, and rabbits. Bald eagles have a life span of up to 30 years in the wild and can reach 50 years in captivity (**AEF 2014; Jacksonville Zoo 2014; Scott 2003a**). Young birds are brown with white spots. After five years of age the adults have a brown-black body, white head, and tail feathers. Bald eagles can weigh from 10-14 lbs. and females tend to be larger than males. They reach sexual maturity at five years, and then find a mate that they will stay with as long as they live (**AEF 2014**).

4.4.2.2. Significance

From 2006-2010, there was an average of 59 active nests out of a total of 107 bald eagle nests surveyed. The nests were located mainly along the edges of the St. Johns River, from which the birds derive most of their food (Appendix 4.4.2.A.). Most of the nests seem to be in use about 57% of the time. Active nests represented 53% (range 47-62%) of the total nests surveyed from 2006-2008. In 2010, the number of active nests increased to 70%. Data for 2009 indicated fewer nests, because of a change in survey protocol starting November 2008 (**Gipson 2014**). After a hiatus of two years, bald eagle nests were surveyed again in 2013 and numbers of active nests had not changed significantly from 2010 (**Gipson 2014**) (Fig. 4.14).

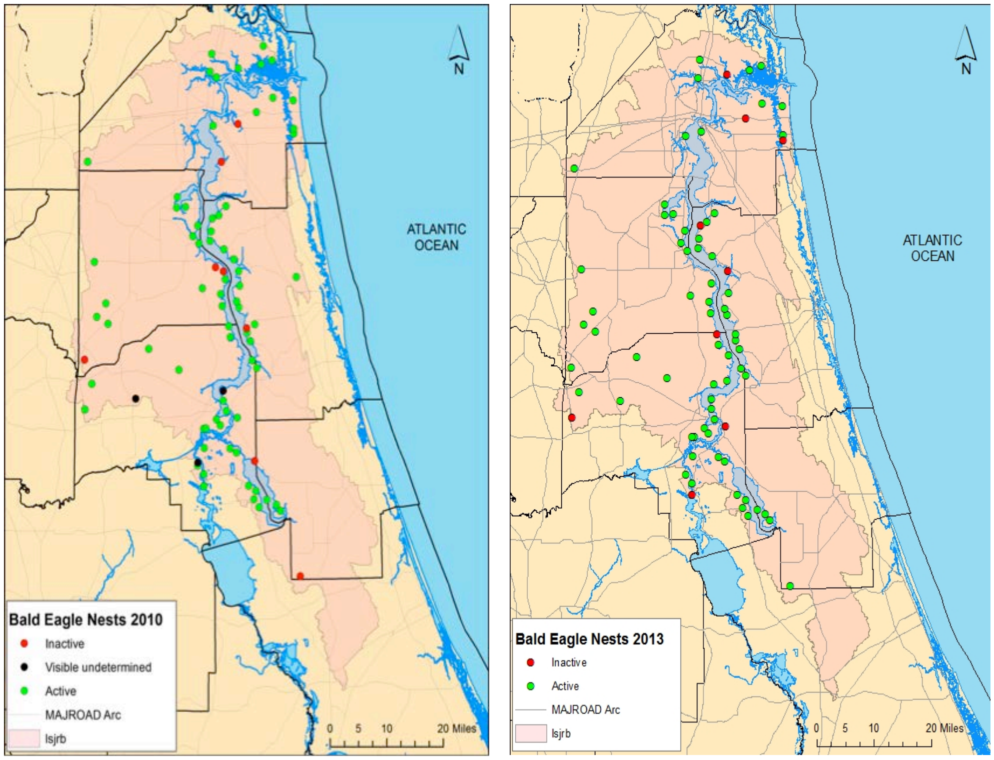


*Figure 4.14 Bald eagle nesting sites in LSJRB 2010 and 2013. (Source data: **Gipson 2014**).*

4.4.2.3. Data Sources & Limitations

Data came from a variety of sources: Audubon Society winter bird counts, FWC, Jacksonville Zoo and Gardens, USFWS and various books and web sites. No new data for the LSJRB area was available from FWCC for 2011/2013 and 2014. Various groups conduct periodic surveys and the state has a five-year management plan (**FWC 2008**) to monitor the eagle's continued welfare (**FWC 2008**; **USFWS 2008d**). Known bald eagle nesting territories within the State of Florida were surveyed by FWC during the 2009 nesting season with fixed-wing or rotary-wing aircraft beginning in late November 2008 and extending through mid-April 2009. Nest locations were determined with the use of aircraft-based GPS units. Accuracy of locations is estimated to be within 0.1 miles of the true location. In 2008, the statewide bald eagle nesting territory survey protocol changed. The protocol change reduces annual statewide survey effort and increases the amount of information gained from the nests that are visited during the survey season. Nest productivity is now determined for a sub-sample of the nests that are surveyed annually. Nest activity and productivity information are critical to determining if the goals and objectives of the Bald Eagle Management Plan are being met (**FWC 2008**).

4.4.2.4. Current Status

In Alaska, there are over 35,000 bald eagles. However, in the lower 48 states of the U.S., there are now over 5,000 nesting pairs and 20,000 total birds. About 300-400 mated pairs nest every year in Florida and constitute approximately 86% of the entire southern population (**Jacksonville Zoo 2014**). Statewide eagle nesting surveys have been conducted since 1973 to monitor Florida's bald eagle population and identify their population trends. Now that this species is no longer listed as Threatened, the primary law protecting it has shifted from the Endangered Species Act to the Bald and Golden Eagle Act (**AEF 2014; USFWS 2008b; USFWS 2008a**). According to Jacksonville winter bird counts by the Duval Audubon Society, numbers sighted have increased significantly ($\tau = 0.754$; $p=6.6E-10$; $n=32$) since the pesticide DDT was banned in the 1960s (Figure 4.15). Taking everything into account, the current STATUS of the Bald Eagles is *satisfactory*, and the TREND is *improving.*

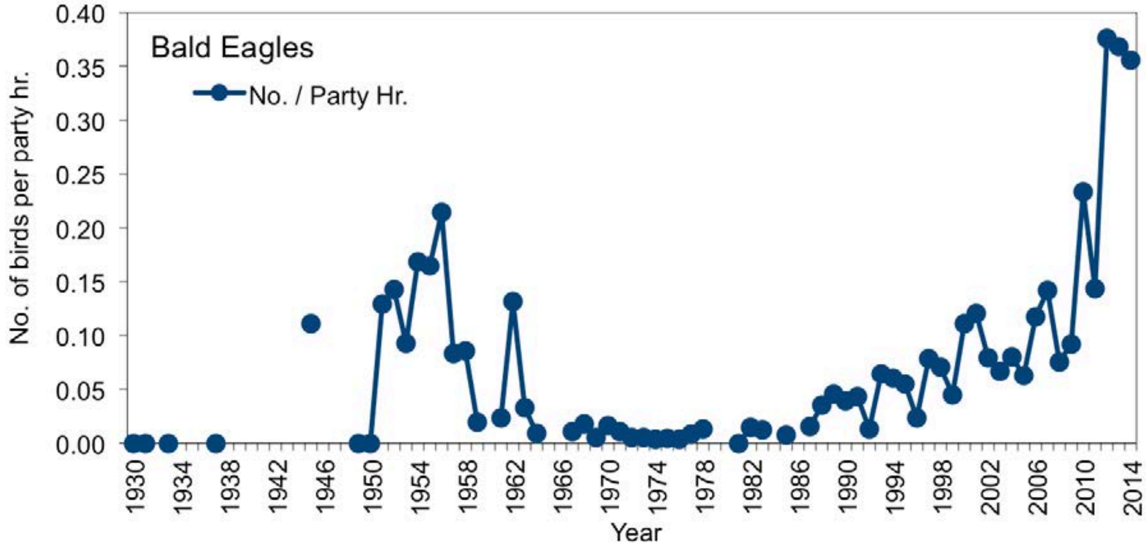


*Figure 4.15 Long term trend in the number of bald eagles counted during winter bird surveys (1929-2014) in Jacksonville, FL Source data. **Audubon 2015** (Appendix 4.4.2.A).*

In a recent Kendall tau correlation analysis of rainfall for the LSJRB, count data for Audubon count circle in Jacksonville was negatively correlated to rainfall, but not significant (τ = -0.095; p=0.280; n=20). The analysis indicated increase in numbers of eagles over time with respect to party hours of effort (τ = 0.611; p=8.38E-05; n=20) and raw numbers (τ = 0.642; p=3.81E-05; n=20), respectively (Figure 4.16/4.17).

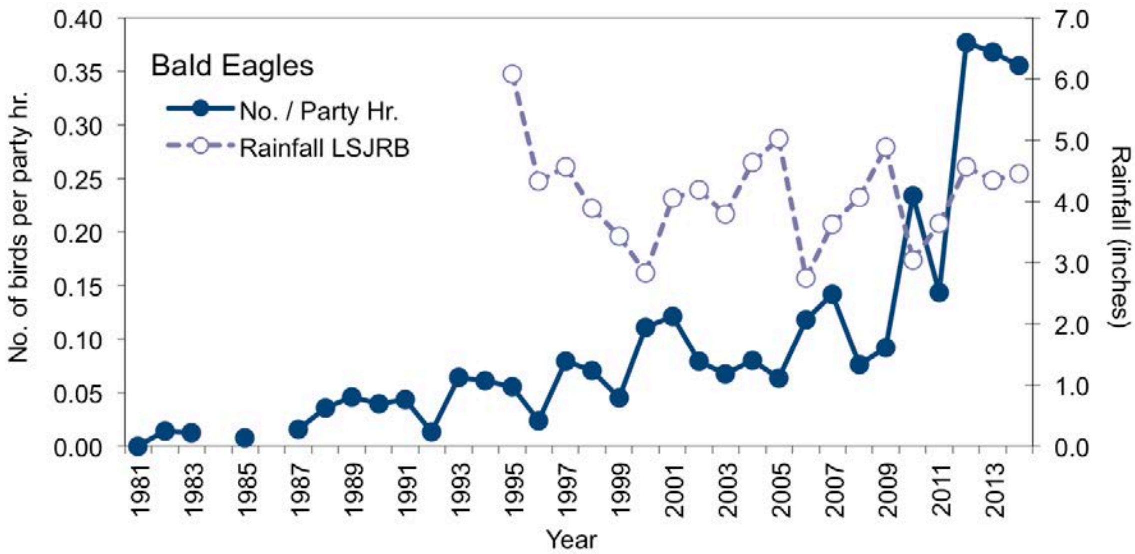


*Figure 4.16 Long term trend in the number of bald eagles counted per party hour and mean monthly rainfall (1981-2014) in Jacksonville, FL Source data: **Audubon 2015** and **SJRWMD 2015a**. (Appendix 4.4.2.A).*

Eagle counts are expressed as numbers of birds per party hour, which accounts for variations due to the effort in sampling the birds. Each group of observers in the count circle for a day is considered one "party" and counts are conveyed together with the number of hours the observers recorded data (note this is not the number of hours of observation multiplied by the number of observers). Number of birds per party hour is defined as the average of the individual number per party hour values for each count circle in the region. In the case of no observations of a given species by a circle within the query region, a value of zero per party hour is averaged.

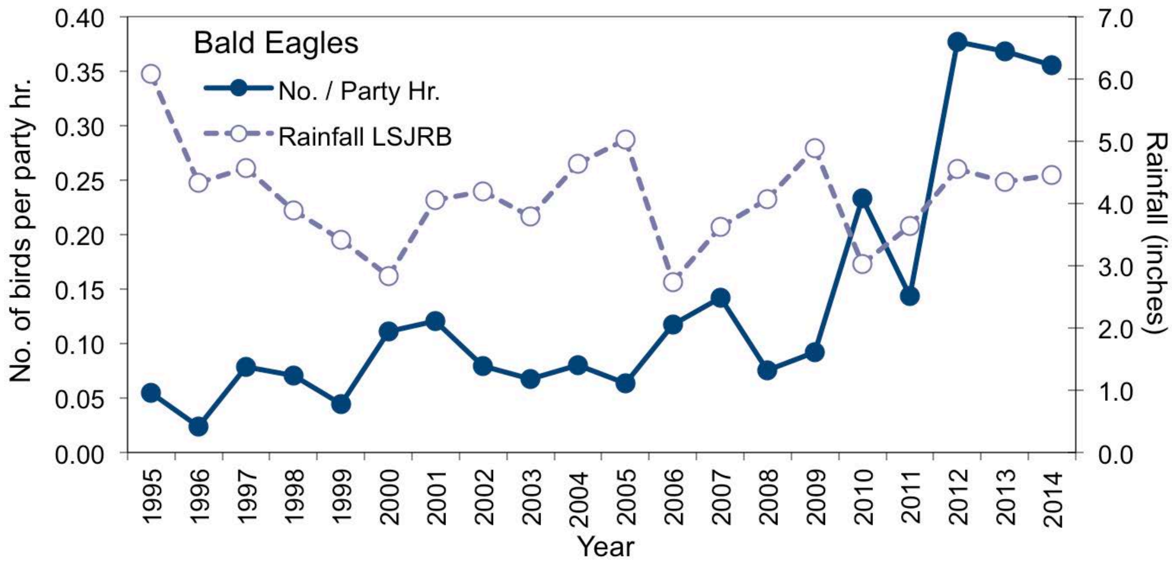


*Figure 4.17. Recent trends in the number of bald eagles counted per party hour and mean monthly rainfall (1995-2014) in Jacksonville, FL Source data: **Audubon 2015** and **SJRWMD 2015a**. (Appendix 4.4.2.A).*

There was a decreasing trend in rainfall 1995-2000, which represents a prolonged period of severe drought (coincides with 1997 El Niño year). Bald eagle numbers surged as the drought deepened probably because of a concentration of their prey as water levels fell. Then, rainfall increased again from 2000-2005 with averages approaching and finally exceeding the norm by 2005. During this period, the number of eagles declined somewhat, presumably because prey resources were more spread out. Also, there was an increase in severe storms (including hurricanes, which usually have a higher potential to affect the U.S during La Niña years) during this time period. Following 2005, another drought ensued (2005-2006), and rainfall declined at a faster rate than previously. Again, eagle numbers surged. From 2006-2009 rainfall increased toward pre drought levels again and eagle numbers declined. Following 2009, another drought cycle began and the eagle numbers increased abruptly. In 2010, rainfall increased and also the number of bald eagles. The dip in eagle numbers in 2010/2011 may have been caused by the unusually cold weather experienced at the time. In 2012, eagle numbers remained at an all-time high with only a slight dip in 2013/2014 (See Appendix: 4.1.7.1.E. rainfall, hurricanes, and El Niño).

4.4.2.5. Future Outlook

Although they have a good future outlook, bald eagles are still faced with threats to their survival. Environmental protection laws, private, state, and federal conservation efforts are in effect to keep monitoring and managing these birds. Even though bald eagles have been delisted, it is imperative that everyone does their part to protect and monitor them, because they are key indicators of ecosystem health. The use of DDT pesticide is now outlawed in the U.S. Threats include harassment by people that injure and kill eagles with firearms, traps, power lines, windmills, poisons, contaminants, and habitat destruction with the latter cause being the most significant (**AEF 2014; FWC 2008; USFWS 2008d**).

4.4.3. Wood Stork (Endangered)

Photo by Wayne Lasch (PBS&J)

4.4.3.1. Description

The wood stork *(Mycteria americana)* was listed as endangered in 1984 and is America's only native stork. The reason for the Endangered Species Act (ESA) listing was declining numbers of nesting pairs from about 20,000 (1930s) to 3,000-5,000 pairs in the 1970s (**Jacksonville Zoo 2015**). Wood storks have recently been recommended for down-listing to threatened status (**USFWS 2007c**). It is a large white bird with long legs and contrasting black feathers that occur in groups. Its head and neck are naked and black in color. Adult birds weight 4-7 lbs. and stand 40-47 inches tall, with a wingspan in excess of 61 inches. Males and females appear identical. Their bill is long, dark and curved downwards (yellowish in juveniles). The legs are black with orange feet, which turn a bright pink in breeding adults.

Wood storks nest throughout the southeastern coastal plain from South Carolina to Florida and along the Gulf coast to Central and South America. Nesting occurs in marsh areas, wet prairies, ditches, and depressions, which are also used for foraging. They feed on mosquito fish, sailfin mollies, flagfish, and various sunfish. They also eat frogs, aquatic salamanders, snakes, crayfish, insects, and baby alligators. They find food by tactolocation (a process of locating food organisms by touch or vibrations). (**USFWS 2002**; **Scott 2003c**). (Add these citations here). Feather analysis of the banded chicks at Jacksonville Zoo suggests that the primary food sources being fed to the chicks is fresh water prey items not zoo food items or estuarine prey. Satellite tracking data to date supports this foraging pattern, with adults feeding primarily on an estuarine prey base prior to nesting, switching to fresh water prey base during chick rearing, and then return to an estuarine diet after chick fledging and during the rest of the year (**Jacksonville Zoo 2015**). Nesting occurs from February to May, and the timing and success is determined primarily by water levels. Pairs require up to 450 lbs. of fish during nesting season. Males collect nesting material, which the female then uses to construct the nest. Females lay from 2-5 eggs (incubation approx. 30 days). To keep eggs cool, parents shade eggs with out-stretched wings and dribble water over them. Wood storks can live up to ten years but mortality is high in the first year (**USFWS 2002**; **Scott 2003c**).

4.4.3.2. Significance

Wood stork presence and numbers can be an indication of the health of an ecosystem. The wood stork is also Florida's most endangered species of wading bird that requires temporary wetlands (isolated shallow pools that dry up and concentrate fish for them to feed on). Scarcity of this specific habitat type due to human alteration of the land causes nesting failures, as has been reported in the Everglades (**Scott 2003c**).

4.4.3.3. Data Sources & Limitations

Data came from Audubon Society winter bird counts from 1962-2010, USFWS surveys and *Southeast U.S. Wood Stork Nesting Effort Database*, FWC/FWRI collaborative work in the SJRWMD area, and Donna Bear-Hull of the Jacksonville Zoo and Gardens from 2000-2013. The Audubon winter bird count area consists of a circle with a radius of ten miles surrounding Blount Island. The USFWS has conducted aerial surveys, which are conservative estimates of abundance and are limited in their use for developing population estimates. However, they still remain the most cost-effective method of surveying large areas. Ground surveys on individual colonies, like at the zoo, tend to be more accurate but cost more on a regional basis (**USFWS 2002**).

4.4.3.4. Current Status

An increasing trend since the 1960s was indicated by the Audubon Society winter bird count data for Jacksonville (Figure 4.18 and Appendix 4.4.3.A).

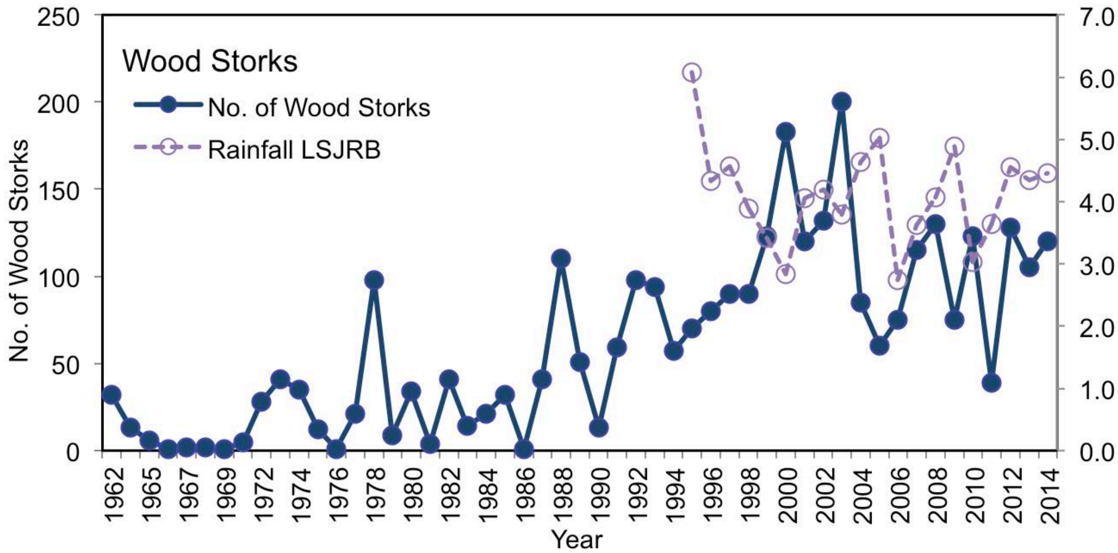


Figure 4.18 Long term trend of the number of Wood Storks counted during winter bird surveys (1961-2014) and mean monthly rainfall Jacksonville, Florida Source data: ***Audubon 2015*** *and* ***SJRWMD 2015a*** *(Appendix 4.4.3.A).*

Rainfall appears to affect wood stork status in several different ways. In the short term (1995-2014), rainfall for the LSJRB was negatively correlated with numbers of wood storks (τ =-0.319; p=0.025; n=20) (Figure 4.19). There was a decreasing trend in rainfall 1995-2000, which represents a prolonged period of severe drought (coincident with 1997 El Niño year). Wood storks surged in numbers as the drought deepened probably because of a concentration of prey as water levels fell. Then from 2000-2002, water levels became too low to support nesting or prey, causing a decline in numbers of wood storks (**Rodgers Jr, et al. 2008a**). Rainfall increased again from 2000-2005 with averages approaching, and finally exceeding, the norm by 2005. During this period the numbers of wood storks continued to decline because of a natural lag in population and food supply. Then, numbers increased again by 2003. Although rainfall continued to increase, numbers of wood storks fell dramatically from 2003-2005. This was probably due to increased storm activity that damaged wood stork colonies, particularly in 2004 when four hurricanes skirted Florida. Also, higher water levels may have caused depressed productivity to breeding adults by dispersing available prey (**Rodgers Jr, et al. 2008b**). Another drought ensued from 2005-2006 and rainfall declined at a faster rate than previously. As before, stork numbers began to increase initially. Then, from 2006-2009, rainfall continued to increase, and wood stork numbers declined. In 2010, following a prolonged cold winter, another cycle of drought began, and wood storks began to increase. Rainfall in the last few years increased to close to normal levels again for the area and the wood stork population rebounded (See Appendix: 4.1.7.1.E. rainfall, hurricanes, and El Niño). Taking everything into account, the current STATUS of the Wood Storks is *satisfactory*, and the TREND is *improving.*

Rainfall data for LSJRB (1995-2014) was negatively correlated with Wood storks when party hours of effort were considered, but this was not significant (τ = -0.242; p=0.068; n=20) (Figure 4.19).

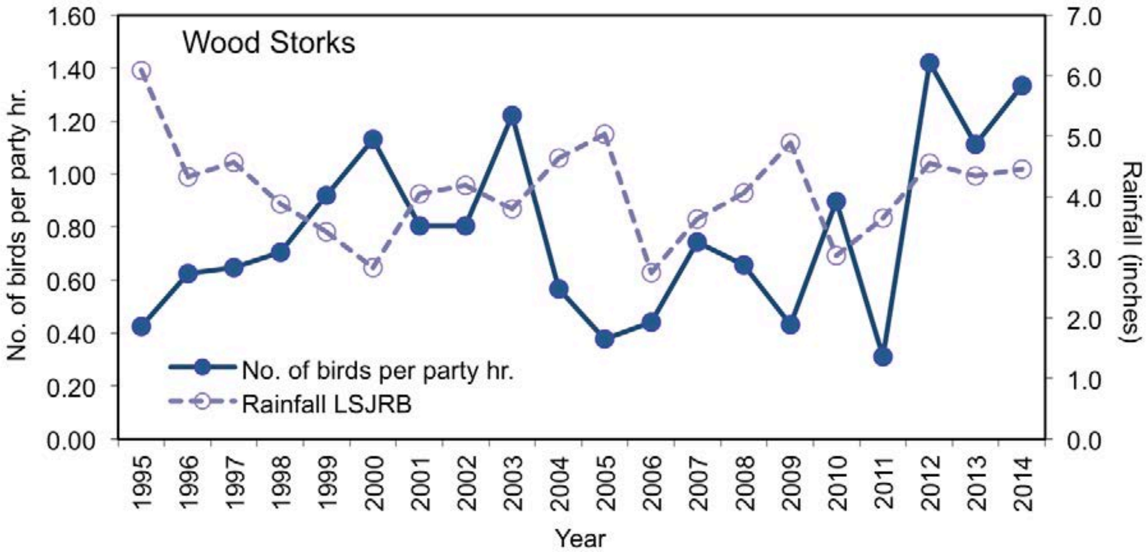


*Figure 4.19 Recent trends in the number of wood storks counted per party hour and mean monthly rainfall (1995-2013) in Jacksonville, FL Source data: **Audubon 2015** and **SJRWMD 2015a**. (Appendix 4.4.2.A).*

Brooks and Dean 2008 describe increasing wood stork colonies in Northeast Florida as somewhat stable in terms of numbers of nesting pairs (Appendix 4.4.3.A). A press release by the USFWS (**Hankla 2007**) stated that the data indicate that the wood stork population as a whole is expanding its range and adapting to habitat changes and for the first time since the 1960s, that there had been more than 10,000 nesting pairs. For a map of the distribution of wood stork colonies and current breeding range in the southeastern U.S. see Figure 4.20.

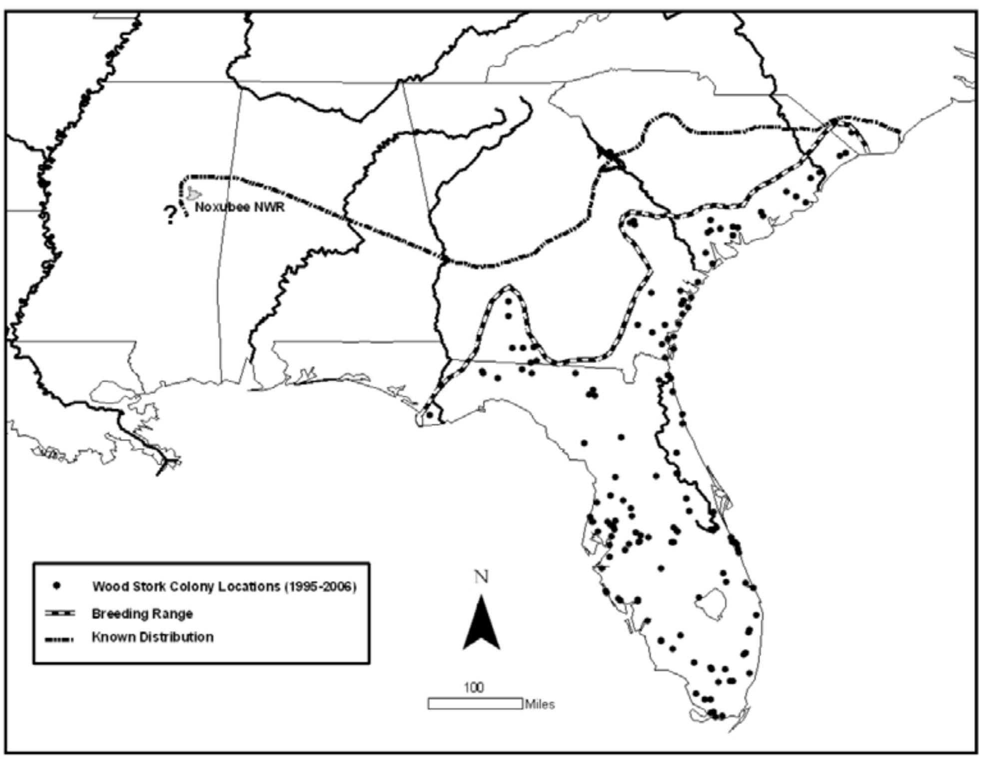


*Figure 4.20. Distribution of wood stork colonies and current breeding range in the southeastern U.S. (**USFWS 2007c**).*

Rodgers Jr, et al. 2008b made a comparison of wood stork productivity across colonies from different regions of Florida. Northern colonies in Florida exhibited greater productivity than those at more southerly latitudes. However, fledgling success was highly variable by year and colony. Local weather conditions and food resources were particularly important in determining nesting and fledgling success. Rainfall during the previous 12-24 months had a significant effect on fledging rates, as did both wetland and non-wetland habitats on fledging rate and colony size (**Rodgers Jr, et al. 2010**).

In the LSJRB, there are several colonies of interest, three of these for which data are available include:

(1) Jacksonville Zoo and Gardens: This colony was formed in 1999 and has continued to show consistent growth. This group continues to have the highest number and productivity of birds in central and north Florida (**Rodgers Jr, et al. 2008a**) (Figure 4.21, 4.22 and Appendix 4.4.3.B). It is considered the most important recently-established rookery in Duval County (**Brooks 2014**). Donna Bear-Hull from the Jacksonville Zoo reported that the 4th year colony doubled in size from 40 breeding pairs (111 fledged chicks) in 2002 to 84 pairs (191 fledged chicks) in 2003. Since 2003, the colony's growth rate has slowed due to space limitations. Local adverse weather conditions (drought) that had an impact on the population and its food supply prevailed in 2005. As food supply was probably concentrated as water levels fell, the colony continued to grow, reaching a high of 117 pairs (267 fledged chicks) in 2006. Then in 2007 a crash occurred and numbers of pairs declined to 47 (58 fledged chicks). In 2008, there was a rebound with the population almost doubling from the previous year to 86 pairs (181 fledged chicks) (**Bear-Hull 2015; USFWS 2004**). In 2009, the nesting and fledgling rates were similar 88 pairs, but 124 fledged chicks (**USFWS 2015**). In 2010, the number of wood storks increased to 107 pairs and 276 fledged chicks. From 2011 to 2013 there was a significant decline in the numbers of fledglings to a low of 35 fledglings from 90 pairs in 2013 (2011: 105 pairs and 213 fledged chicks; 2012: 106 pairs and 147 fledged chicks. Currently this population appears to be close to carrying capacity, and with declining numbers of nests (2014: 88 nests, 74% success rate; 2013: 90 nests, 30% success rate; 2012: 106 nests, 76% success rate) (**Bear-Hull 2015**).

In 2003, the zoo formed a conservation partnership with USFWS to monitor the birds/nests more closely (twice weekly). Since that time, the zoo has banded 11 chicks (of 1,060 fledglings) and nine adults. In addition, four adults have been fitted with satellite monitoring tags. The nine banded adults returned every year to the zoo site until 2007, some did not perhaps going to other rookeries. Satellite tracking data to date supports this foraging pattern, with adults feeding primarily on an estuarine prey base prior to nesting, switching to fresh water prey base during chick rearing, and then return to an estuarine diet after chick fledging and during the rest of the year (**Jacksonville Zoo 2015**).

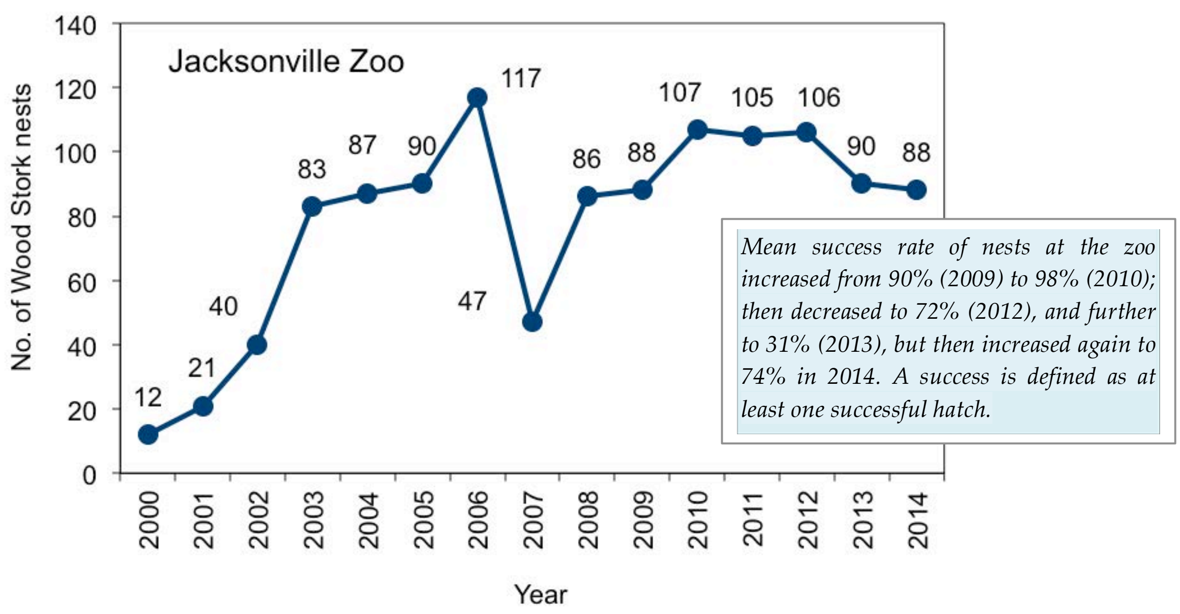


Figure 4.21. Number of wood stork nests at Jacksonville Zoo (2003-2014)
*Source data: **Bear-Hull 2015; USFWS 2005; USFWS 2007c**.*

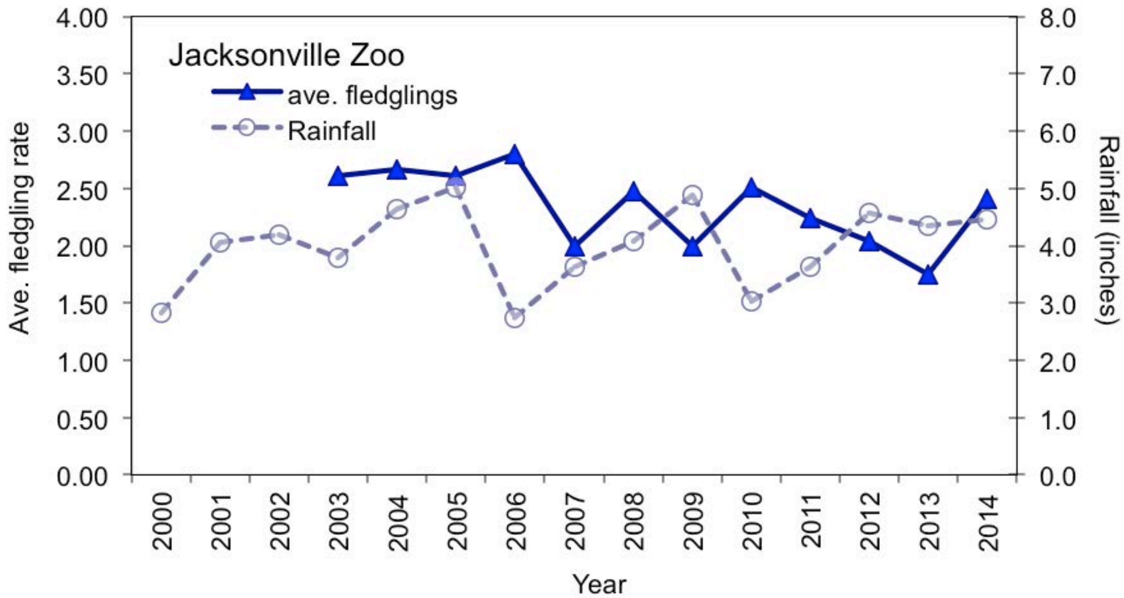


Figure 4.22. Wood stork productivity chicks/nest/yr. at Jacksonville Zoo (2003-2014) and mean monthly rainfall.
*Source data: **Bear-Hull 2015; Rodgers Jr. 2011; SJRWMD 2015a; USFWS 2005; USFWS 2007c**.*

(2) Dee Dot Colony: In 2005, the USFWS reported that there were over a hundred nests in this cypress swamp impounded lake in Duval County. However, the fledgling rate was low (1.51 chicks/nest in 2003, and 1.42 chicks/nest in 2004). Fledgling rates greater than two chicks/nest/year are considered acceptable productivity (**USFWS 2005**). Furthermore, the number of nests decreased from 118 in 2003 to 11 in 2007. This decline was probably due to nesting failure in 2003 caused by winds greater than about 20 mph and rain in excess of 1.5 inches/hr.) (**Rodgers Jr, et al. 2008b**; **Rodgers Jr, et al. 2008a**). Fledgling rate improved from an average of 1.75 chicks/nest/year (2003-2005) to 2.11 chicks/nest/year in 2006 (**USFWS 2007c**). The rate then declined to 1.45 (2007), and rose back to 2.07 (2008) (**Rodgers Jr, et al. 2008b**; **Rodgers Jr, et al. 2008a**). Rainfall continued an upward trend; although the colony was active (determined by aerial survey); data on wood storks numbers were unavailable for 2009-2013 (Figures 4.23 and 4.24). In 2014, the colony consisted of 170 active wood stork nests, determined from aerial photographs.

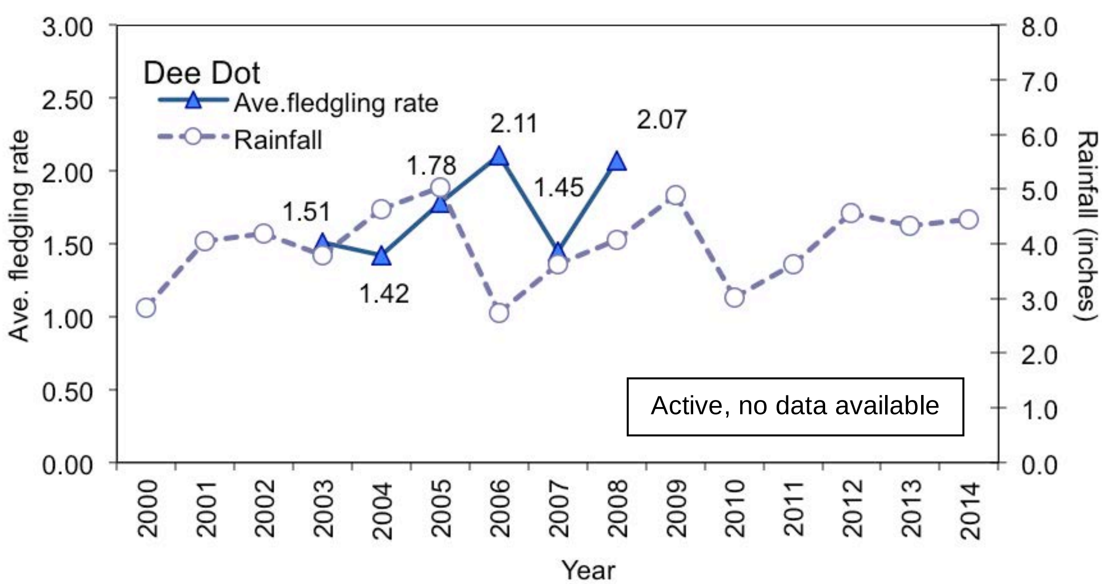


Figure 4.23. Wood stork productivity (chicks/nest/year) at Dee Dot (2000-2014) and mean monthly rainfall.
*Source data: **Rodgers Jr, et al. 2008b; SJRWMD 2015a; USFWS 2005; USFWS 2007c**.*

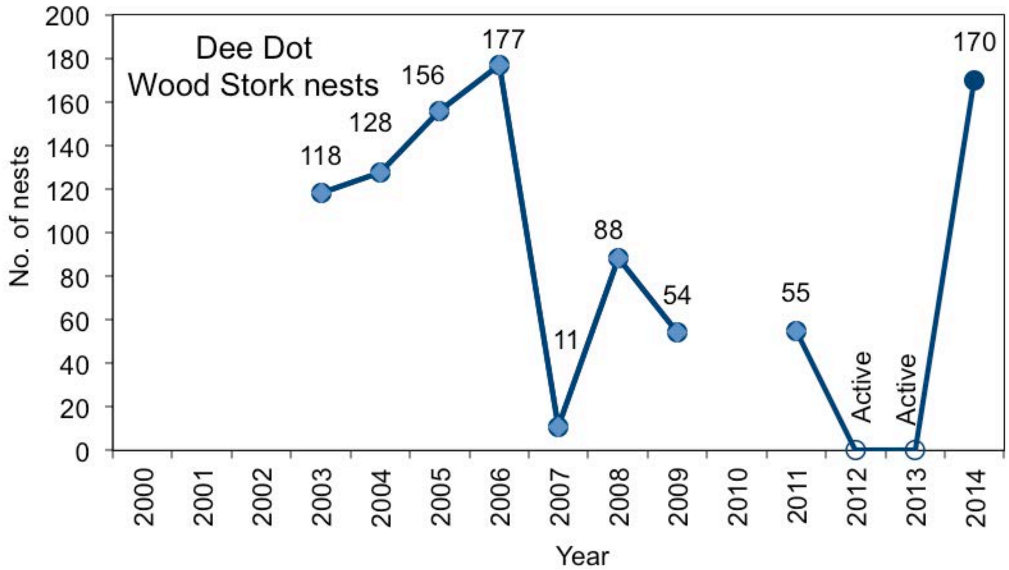


*Figure 4.24. Number of wood stork nests at Dee Dot (2003-2013) Note: there were no data for 2010, 2012, and 2013. Source data: **Rodgers Jr, et al. 2008a; Rodgers Jr, et al. 2008b; USFWS 2015**.*

(3) Pumpkin Hill Creek Preserve State Park: This colony in Duval County had 42 nests in 2005 and 2008 (down from 68 in 2003) and fledgling rate averaged 1.44 chicks/nest/year in those years (**USFWS 2005**). Lack of rainfall during the breeding season (March to August) resulted in no water below the trees in 2004 that contributed to nest failures. Flooding following post-August 2004 hurricane season resulted in a return of breeding storks in 2005 (**Rodgers Jr, et al. 2008a**). In 2009, the colony was described as being active, but no data were available (**Brooks 2014; USFWS 2015**). This site was inactive during 2010 to 2013 (Figures 4.25 and 4.26).

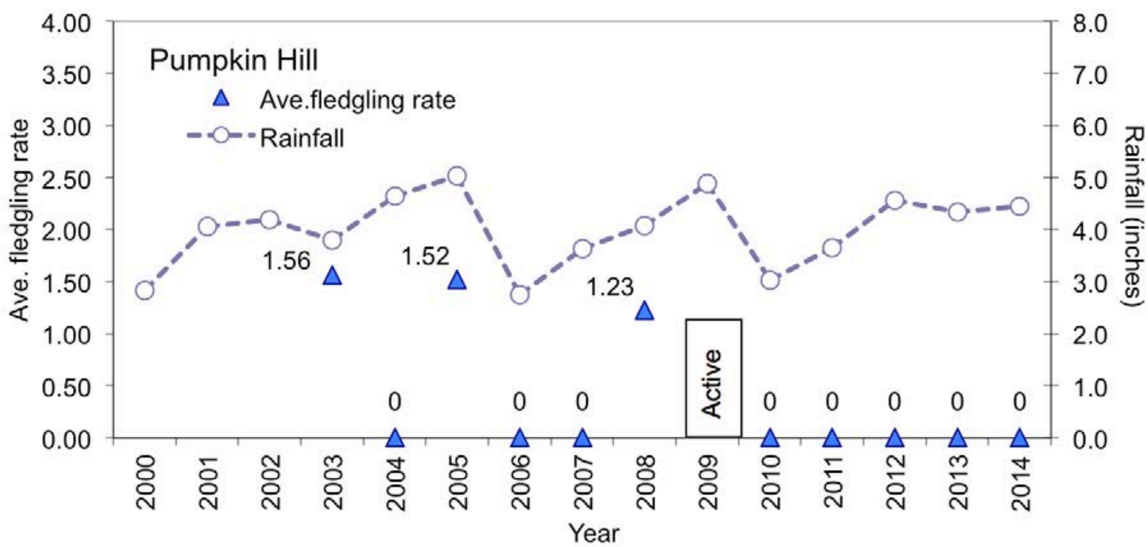


*Figure 4.25. Wood stork productivity (chicks/nest/year) at Pumpkin Hill (2003-2014) and mean monthly rainfall. There are two colonies at this site, which is characterized by cypress-dominated domes. In 2004, the period 2006 to 2007, and from 2010-2014 no wood stork activity has been documented at this site. In 2009, the colony was described as being active, but no data was available. Source data: **Rodgers Jr, et al. 2008a; Rodgers Jr, et al. 2008b; USFWS 2015; SJRWMD 2015**.*

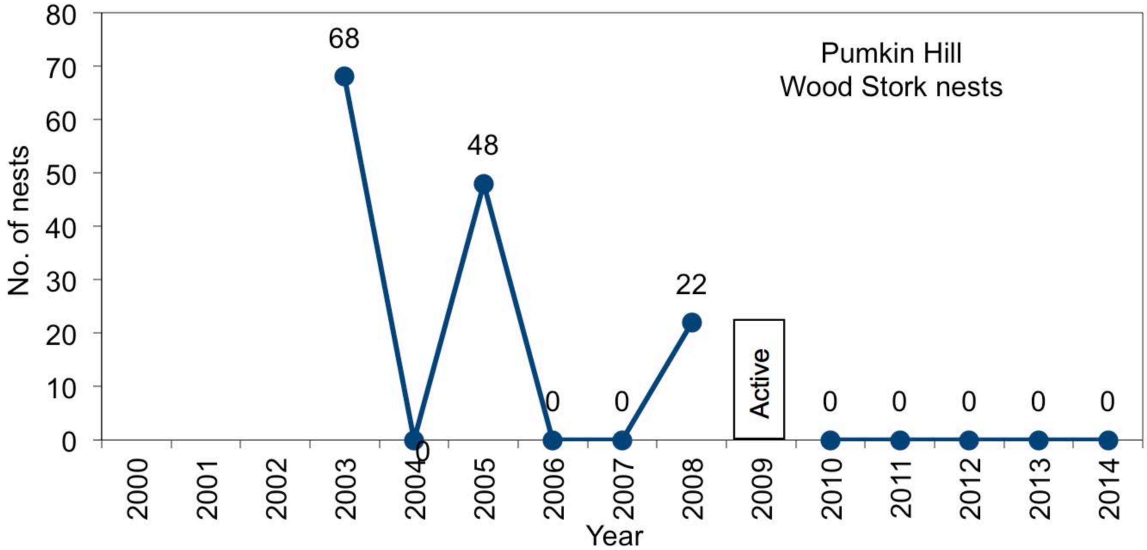


Figure 4.26. Number of wood stork nests at Pumpkin Hill (2003-2014). In 2004, the period 2006 to 2007, and from 2010-2014 no wood stork activity has been documented at this site. In 2009, the colony was described as being active, but no data was available. Source data: ***Rodgers Jr, et al. 2008a; Rodgers Jr, et al. 2008b; USFWS 2015****.*

4.4.3.5. Future Outlook

Historically, the wood stork breeding populations were located in the Everglades but now their range has almost doubled in extent and moved further north. The birds continue to be protected under the Migratory Bird Treaty Act and state laws. Although they are not as dependent on the Everglades wetlands, wetlands in general continue to need protection. Threats continue to exist such as contamination by pesticides, harmful algae blooms, electrocution from power lines and human disturbance such as road kills. Adverse weather events like severe droughts, thunderstorms or hurricanes also threaten the wood storks. The USFWS Wood Stork Habitat Management Guidelines help to address these issues. Continued monitoring is essential for this expanding and changing population (**USFWS 2007c**).

4.4.4. Piping Plover (Threatened)

Source: **USFWS 2007b**

4.4.4.1. Description

The piping plover *(Charadrius melodus)* has been a protected species under the ESA since January 10, 1986 and is threatened along the Atlantic Coast. There are three populations of the piping plover, The Great Plains, Great Lakes and Atlantic Coast. The piping plover breeds on coastal beaches from Newfoundland and southeastern Quebec to North Carolina. These birds winter primarily on the Atlantic Coast from North Carolina to Florida, although some migrate to the Bahamas and West Indies. Piping plovers were common along the Atlantic Coast during much of the 19th century, but nearly disappeared due to excessive hunting for the millinery trade. Following passage of the Migratory Bird Treaty Act in 1918, numbers recovered to a 20th century peak, which occurred during the 1940s. The current population decline is attributed to increased development and recreational use of beaches since the end of World War II. The most recent surveys place the Atlantic population at less than 1,800 pairs (**USFWS 1996**). Its name *Charadrius melodus* comes from its call notes, plaintive bell-like whistles that are often heard before the bird is seen.

Piping plovers are small, stocky, sandy-colored shore birds that resemble sandpipers. Adults have yellow-orange legs, a black band across the forehead from eye to eye, and a black ring around the base of the neck. Piping plovers run in short starts and stops, blending into the pale background of open, sandy habitat on outer beaches where they feed and nest. In late March or early April, they return to their breeding grounds, where a pair then forms a depression in the sand somewhere on the high beach close to the dunes (**USFWS 2007b**). Normally, new pairs are formed each breeding season. The males will perform aerial displays to attract the attention of unpaired females during courtship (**Audubon 2015**) Sometimes their nests are found lined with small stones or fragments of shell (**USFWS 2007b**). Usually nests are found close to, but not in, areas of patchy vegetation and often close to a log rock or other prominent object (**Audubon 2015**). The adults, both male and female, incubate the eggs for about four weeks, after which four eggs are hatched. The eggs, like the piping plovers, are camouflaged by the surrounding sand or cobblestones and are rarely seen unless stepped on. The surviving young are flying in about 30 days. When on the forage, they look for marine worms, crustaceans, and insects that they pluck from the sand. When the young are out foraging and a predator or intruder comes close, the young will squat motionless on the sand while the parents attempt to attract the attention of the intruder, often by faking a broken wing. However, if the adults spend too much time doing this, the eggs and chicks become vulnerable to predators and to overheating in the hot sun (**Scott 2003b**; **USFWS 2007b**).

4.4.4.2. Significance

The piping plover is one of many species that have suffered from drastic ecosystem changes, like river channelization, impoundment, and shoreline development (**Stukel 1996**). Critical wintering habitat designated by USFWS in 2001 for the bird exists from Nassau Sound to the St. Johns River.

4.4.4.3. Data Sources & Limitations

Data came from Audubon winter counts for Jacksonville in addition to a variety of books, reports and web sites. The winter bird count area consists of a circle with a radius of ten miles surrounding Blount Island.

4.4.4.4. Current Status

Current wintering populations in Florida showed decline attributed mainly to increased development and recreational use of beaches in the last sixty years. In 2005, Bird Life International estimated the entire piping plover population at 6,410, comprising of three groups- Atlantic Coast (52%), Great Plains (46%), and Great Lakes (2%). Totals in the Atlantic Coast population increased from 1,892 birds in 1991 to 3,350 birds in 2003. Totals for the Great Plains area increased from 2,744 birds in 1991 to 3,284 birds in 1996, then decreased to 2,953 birds in 2001. In the Great Lakes region, the population increased from 32 birds in 1991 to 110 birds in 2004. Overall, there has been a total population increase of 9.5% (using the 1996 data) to 32.6% (using the 1991 data). However, the 1996-2001 data indicate a slight decline of the Great Plains population. The increases are the result of sustained management initiatives (**Audubon 2010**; **BirdLife 2008**). Although numbers of birds per party hour appear to have increased slightly since the mid-1980s, the Jacksonville data (Figure 4.27) did not indicate that a significant trend was present over the long term (1929-2014). When considering the intermediate term (1985-2014) there was an increasing trend ($\tau = 0.278$; $p=0.015$; $n=30$) (Figure 4.28). In the short term (1995-2014) there was no significant trend indicated (Appendix 4.4.5).

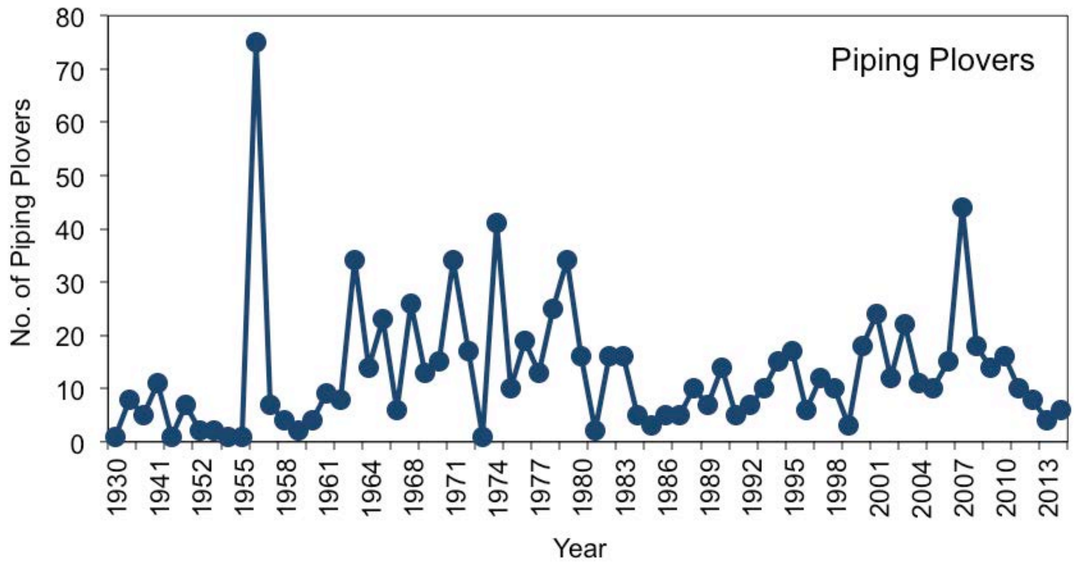


Figure 4.27. Numbers of piping plovers counted during winter bird surveys (1930-2014) in Jacksonville, Florida. Source data: ***Audubon 2015****.*

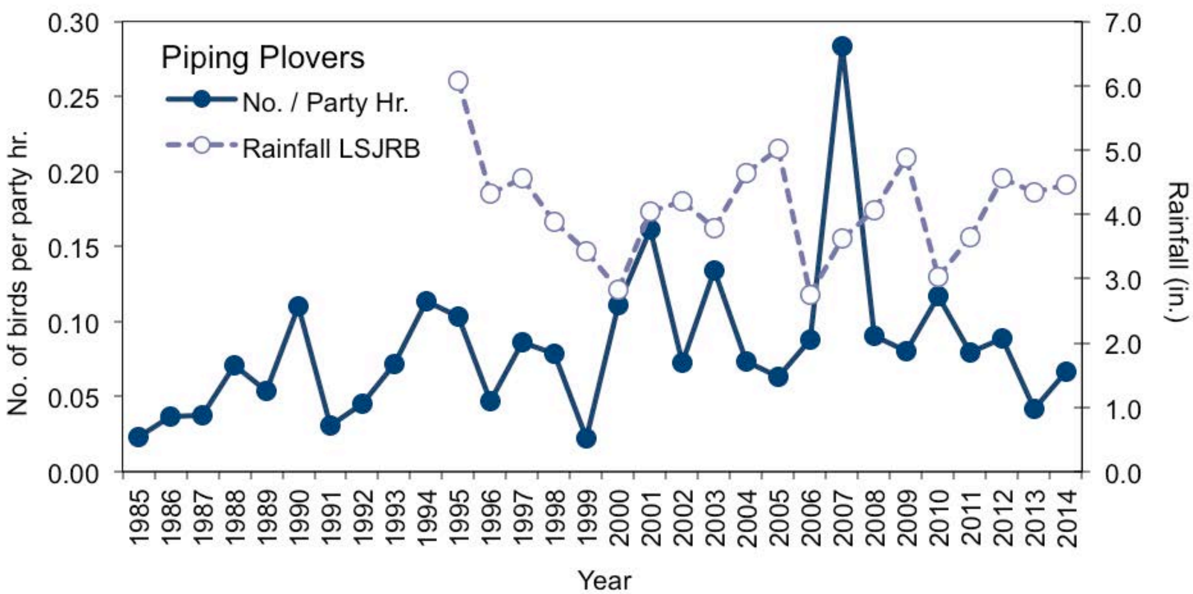


Figure 4.28. Recent trends in the number of piping plovers counted per party hour and rainfall (1985-2014) and mean monthly rainfall in Jacksonville, Florida. Source data: ***Audubon 2015*** *and* ***SJRWMD 2015a***

4.4.4.5. Future Outlook

The piping plover can be protected by respecting all areas which are fenced or posted for protection of wildlife, and by not approaching piping plovers or their nests. Pets should be kept on a leash where shorebirds are present. Trash or food scraps should not be left behind or buried at beaches because they attract predators, which may prey on piping plovers' eggs or chicks. Structures called exclosures are sometimes erected around a nest to protect the eggs from predators. The Endangered Species Act provides penalties for taking, harassing, or harming the piping plover and affords some protection to its habitat. By protecting the piping plover, other species such as the federally endangered roseate tern (Florida population is listed as threatened), the threatened northeastern beach tiger beetle (not found in Florida), the threatened seabeach amaranth (not reported from Florida), the endangered least tern, the common tern, the black skimmer, and the Wilson's plover, may also benefit from the piping plover protection efforts (**Scott 2003b**; **USFWS 2007b**).

4.4.5. Shortnose Sturgeon (Endangered)

Source: USFWS

4.4.5.1. Description

The Shortnose sturgeon *(Acipenser brevirostrum)* is a native species historically associated with rivers along the east coast of U.S. from Canada, south to Florida. The fish tend to be found in larger populations in more northerly rivers. The Shortnose sturgeon was listed as endangered in 1967. It is a semi-anadromous fish that swims upstream to spawn in freshwater before returning to the lower estuary, but not the sea. The species is particularly imperiled because of habitat destruction and alterations that prevent access to historical spawning grounds. The St. Johns River is dammed in the headwaters, heavily industrialized and channelized near the sea, and affected by urbanization, suburban development, agriculture, and silviculture throughout the entire basin. Initial research conducted by the National Marine Fisheries Service in the 1980s and 1990s culminated in the Shortnose Sturgeon Recovery and Management Plan of 1998 (**FWRI 2014c; NMFS 1998**).

"Anadromous" fish live in the ocean, but return to freshwater to spawn.

4.4.5.2. Significance

There are no legal fisheries or by-catch allowances for shortnose sturgeon in U.S. waters. Principal threats to the survival of this species include blockage of migration pathways at dams, habitat loss, channel dredging, and pollution. Southern populations are particularly at risk due to water withdrawal from rivers and ground waters and from eutrophication (excessive nutrients) that directly degrades river water quality causing loss of habitat. Direct mortality is known to occur from getting stuck on cooling water intake screens, dredging, and incidental capture in other fisheries (**NMFS 1998**).

4.4.5.3. Data Sources & Limitations

Information on shortnose sturgeon in literature is limited to a few specimen capture records. Information sources included books, reports and web sites. Shortnose sturgeons have been encountered in the St. Johns River since 1949 in Big Lake George and Crescent Lake (**Scott 2003d**). Five shortnose sturgeons were collected in the St. Johns River during the late 1970s (**Dadswell, et al. 1984**) and, in 1981, three sturgeons were collected and released by the FWC. All these captures occurred far south of LSJRB in an area that is heavily influenced by artesian springs with high mineral content. None of the collections was recorded from the estuarine portion of the system (**NMFS 1998**). From 1949-1999, only 11 specimens had been positively identified from this system. Eight of these captures occurred between 1977 and 1981. In August 2000, a cast net captured a shortnose sturgeon near Racy Point just north of Palatka. The fish carried a tag that had been attached in March 1996 by Georgia Department of Natural Resources near St. Simons Island, Georgia. During 2002/2003 an intensive sampling effort by researchers from the FWRI captured one 1.5 kg (3.3 lbs.) specimen south of Federal Point, again near Palatka. As a result, FWRI considers it unlikely that any sizable population of shortnose sturgeon currently exists in the St. Johns River. In addition, the rock or gravel substrate required for successful reproduction is scarce in the St. Johns River and its tributaries. Absence of adults and marginal habitat indicate that shortnose sturgeons have not actively spawned in the system and that infrequent captures are transients from other river systems (**FWRI 2014c**)

4.4.5.4. Current Status

The species is likely to be declining or almost absent in the LSJRB (**FWRI 2014c**).. Population estimates are not available for the following river systems: Penobscot, Chesapeake Bay, Cape Fear, Winyah Bay, Santee, Cooper, Ashepoo Combahee Edisto Basin, Savannah, Satilla, St. Marys and St. Johns River (Florida). Shortnose sturgeon stocks appear to be stable and even increasing in a few large rivers in the north but remain seriously depressed in others, particularly southern populations (**Friedland and Kynard 2004**).

4.4.5.5. Future Outlook

The Shortnose Sturgeon Recovery and Management Plan (**NMFS 1998**) identifies recovery actions to help reestablish adequate population levels for de-listing. Captive mature adults and young are being held at Federal fish hatcheries operated by the USFWS for breeding and conservation stocking.

4.4.6. Florida Scrub-Jay (Threatened)

Source: FWC

4.4.6.1. Description

The Florida scrub-jay *(Aphelocoma coerulescens)* was listed as threatened in 1987. It is 12 inches long and weighs 2.5-3 ounces. Adults have blue feathers around the neck that separate the whiter throat from the gray under parts. They have a white line above the eye that often blends into their whitish forehead. The backs are gray and the tails are long and loose in appearance. Scrub-jays up to five months old have a dusky brown head and neck and shorter tail. In the late summer and early fall, it is almost impossible to differentiate the juveniles from the adults. During this time juveniles undergo a partial molt of body feathers. Adult males and females have identical plumage, but are set apart by a distinct "hiccup" call vocalized only by the females (**BCNRM 2014**). **FWC 2014a** describes the bird as partly resembling the blue-jay *(Cyanocitta cristata)*. The Florida scrub-jay differs from a blue-jay in that it is duller in color, has no crest, has longer legs and tail, and lacks the bold black and white marking of the blue-jay (**BCNRM 2014**)). As one of the few cooperative breeding birds in the United States, the fledgling scrub-jays typically remain with the breeding pair in their natal territory as "helpers" (**BCNRM 2014**). These family groups range from two to eight birds. Pre-breeding groups usually just have one pair of birds with no helpers or families of three or four individuals. The helpers within the groups participate by looking out for predators, predator-mobbing, helping with territorial defense against neighboring scrub-jay groups, and the feeding of both nestlings and fledglings. On average, Florida scrub-jays typically do not begin mating until they are at least 2-3 years of age. Nestlings can be observed from March 1 through June 31 and are usually found in shrubby oaks 1-2 meters (3-7 ft.) in height. Each year a new nest is built, usually about 1-3 meters (3-10 ft.) above ground and structured as a shallow basket of twigs lined with palmetto fibers (**FWC 2014a**). Most nests contain three or four eggs, which are incubated for 17-18 days. Fledging occurs 16-19 days after hatching. The fledglings are reliant on the adults for food for up to two months after leaving the nest. Once they become independent, Florida scrub-jays live out their entire lives within a short distance of where they were hatched (**BCNRM 2014**).

Florida scrub-jay populations are found in small isolated patches of sand pine scrub, xeric oak scrub, and scrubby flat woods in peninsular Florida. Scrub-jays occupy territories averaging 22 acres in size, but they hunt for food mostly on or near the ground. Their diet is made up of mostly terrestrial insects, but may also include tree frogs, lizards, snakes, bird eggs and nestlings, and juvenile mice. Acorns form one of the most important foods from September to March (**BCNRM 2014**).

4.4.6.2. Significance

Populations occur on the southwest boundary of the LSJRB (**USFWS 2007a**) and add to the overall species diversity in the basin .

4.4.6.3. Data Sources & Limitations

Information was gathered from books, reports and web sites, but limited data were available for the LSJRB.

4.4.6.4. Current Status

The population of the scrub-jays has declined by 90% over the last century and by 25% since 1983. In 1983 the estimated population was 8,000 birds according to the Audubon Society (**Audubon 2014a**). A single bird was reported in Jacksonville in 1950/51 (**Audubon 2014b**) and three birds were observed in winter of 2000 (**Audubon 2014c**). The species is now being legally protected by the USFWS and the FWC. The Florida scrub-jay is being studied in their natural habitats and in areas undergoing rapid development. In addition, land acquisition activities have been ongoing in Florida to purchase the remaining privately-owned oak scrub habitat in order to conserve critical habitat for the scrub-jay (**FWC 2014a**). Since the late 1980s, scrub-jays have been reported to have been extirpated (locally extinct since people settled in the area) from Broward, Dade, Duval, Gilchrist, Pinellas, St. Johns, and Taylor counties (**USFWS 1990**). A 1992-1993 survey indicated that scrub-jays were also extirpated from Alachua and Clay counties. Scrub-jays are still found in Flagler, Hardee, Hendry, Hernando, Levy, Orange, and Putnam counties, but ten or less pairs remained in these counties and were considered functionally extirpated (**Fitzpatrick, et al. 1994**). Subsequent information indicated that at least one breeding pair remained in Clay County as late as 2004 and an individual bird was observed in St. Johns County in 2003 (**USFWS 2007a**). **Fitzpatrick, et al. 1994** indicated that scrub-jays have been noticeably reduced along their former range all along the Atlantic coast (Figure 4.29).

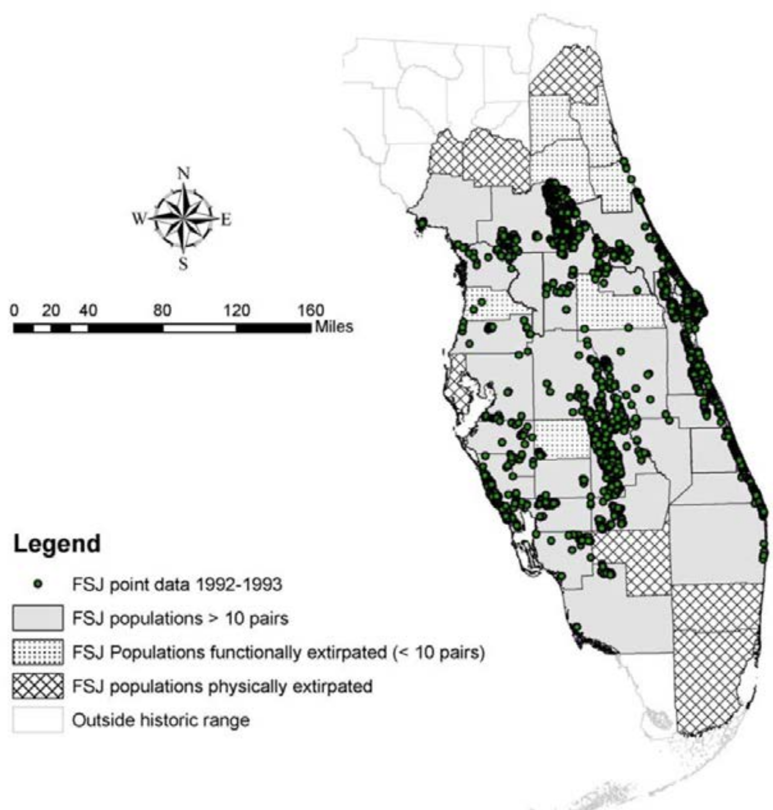


*Figure 4.29. Historical vs. current scrub-jay distribution. Stripping and/or shading reflect known new sightings of scrub-jays since the 1992-1993 statewide survey. Source: **USFWS 2007a**.*

4.4.6.5. Future Outlook

Florida Audubon developed a Recovery Resolution Plan (**USFWS 1990**) for the Florida scrub-jay, and has also played a big role in their protection. FWC suggests the following measures to help protect Florida scrub-jays:

1) *The best protection is to protect scrub-jay populations on managed tracts of optimal habitat.*
2) *Provide habitat by planting, protecting, and growing patches of shrubby scrub live oak, Chapman's oak, myrtle oak, and scrub oak on your property. Also, maintain landscaping at a maximum height of 3 meters (10 ft.) if you live on or near scrub-jay habitat.*
3) *Encourage passage and strict enforcement of leash laws for cats and dogs in your community and protect areas being used by nesting scrub-jays from domestic animals, especially cats.*
4) *Limit pesticide use because pesticides may limit or contaminate food used by the jays.*
5) *Report any harassment of Scrub jays or their nests to 1-888-404-FWCC (3922).*

4.4.7. Eastern Indigo Snake (Threatened)

Source: USFWS.

4.4.7.1. Description

The Eastern Indigo snake *(Drymarchon corais couperi)* is non-venomous, and the largest snake found in the U.S. It is protected by federal (1978) and state laws (1971). Typically an adult is 1.5-2 m (5-6 ft.) long, and 5-7 cm (2-3 inches) in girth. The range of these reptiles is currently restricted to Florida and southeastern Georgia with isolated populations in other parts of Georgia and in Alabama. Also, Indigos are most common on the Upper and Lower Florida Keys. Breeding occurs between November and April (**Dodd Jr and Barichivich 2007**; **Scott 2003e**).

4.4.7.2. Significance

Indigos are habitat generalists that require large areas of unsettled land from 25-450 acres in which to roam, depending on the season (**Hyslop 2007**; **Hyslop, et al. 2006**; **Moler 1985**; **Zappalorti 2008**). Habitats used vary widely. Sandhill communities are preferred, but indigo snakes can also be found in pine flatwoods, scrub, coastal strand ecosystems and orange groves (**Scott 2003e**). The snake is diurnal and will subdue and swallow prey whole, feeding on water snakes and a large variety of small prey along the edges of waterways and marshes. Indigo snakes are well known for using gopher tortoise burrows for refuge (**Dodd Jr and Barichivich 2007**; **Scott 2003e**). However, gopher tortoise populations have been severely reduced in some areas which may affect indigos (**Scott 2003e**).

4.4.7.3. Data Sources & Limitations

Information was gathered from books, reports and web sites but there were limited data available for LSJRB. **Dodd Jr and Barichivich 2007**) mention that most information regarding habitat, use and requirements for the indigo snake is found in unpublished, non-peer reviewed, and largely inaccessible agency reports.

4.4.7.4. Current Status

The literature indicates declining populations throughout its range because of habitat destruction and fragmentation from development, vehicle collisions, gassing burrows (illegal activity 3925.002 FAC), illegal collection and mortality caused by domestic dogs and humans (**Lawler 1977**; **Moler 1992**; **Scott 2003e**; **Stevenson, et al. 2003**).

4.4.7.5. Future Outlook

The focus of habitat protection should be on large non-fragmented tracts of land of about 2,500 acres in size (**Dodd Jr and Barichivich 2007**; **Moler 1992**). **Moler 1992** proposes that mitigation funds from developments that unavoidably eliminate habitat should be pooled to allow for such large land acquisitions. In north Florida's xeric habitats the future status of indigos is closely linked to that of gopher tortoises (**Dodd Jr and Barichivich 2007**; **Moler 1992**; **Scott 2003e**). Rebuilding the tortoise populations will benefit the indigo snake. Furthermore, **Moler 1992** asserts that laws against violations such as "gassing" of tortoise burrows should be strongly enforced. Recent work in southeast Georgia has focused on trapping methods, survival rates, and seasonal shifts in shelter and microhabitat use (**Hyslop, et al. 2009a; Hyslop, et al. 2009b; Hyslop, et al. 2009c**).

4.5. Non-native Aquatic Species

4.5.1. Description

The invasion and spread of non-native, or "exotic," species is currently one of the most potent, urgent, and far-reaching threats to the integrity of aquatic ecosystems around the world (**NRC 1995**; **NRC 1996**; **NRC 2002**; **Ruckelshaus and Hays 1997**). Non-native species can simply be defined as "any species or other biological material that enters an ecosystem beyond its historic, native range" (**Keppner 1995**).

Protection from and management of aquatic species occurs at the federal and state levels. At the federal level, impairment by invasive species is not recognized under the Clean Water Act (ELI 2008). USACE in Jacksonville leads invasive species management with the Aquatic Plant Control Operations Support Center and the Removals of Aquatic Growth Program. The US Department of Agriculture Animal and Plant Health Inspection Services is charged with protection from invasive species (**ELI 2008**).

In Florida, management of invasive species is coordinated by Florida Fish and Wildlife Commission's Aquatic Plant Management Program. In 1994, Florida Department of Environment (FDEP) included a TMDL waterbody impairment category of "WEED- exotic and nuisance aquatic plants density impairing waterbody" (**ELI 2008**). However, FDEP has yet to develop a TMDL for this category. FWC regulates import of vertebrate and invertebrate aquatic species, Florida Department of Agriculture and Consumer Services (FDACS) contributes to prevention of invasive species with importation regulation. Water management districts also contribute with control and restoration programs (**ELI 2008**). Non-profit organizations such as the First Coast Invasive Working group coordinate invasive species removal events and education outreach.

4.5.2. Significance

The transport and establishment of non-native aquatic species in the St. Johns River watershed is significant due to a number of ecosystem, human health, social, and economic concerns.

4.5.2.1. Ecosystem Concerns

"Generalizations in ecology are always somewhat risky, but one must be offered at this point. The introduction of exotic (foreign) plants and animals is usually a bad thing if the exotic survives; the damage ranges from the loss of a few native competing species to the total collapse of entire communities" (**Ehrenfeld 1970**). The alarming increase in the number of documented introductions of non-native organisms is of pressing ecological concern (**Carlton and Geller 1993**). This concern is supported by the evidence that non-native species, within just years of introduction, are capable of breaking down the tight relationships between resident biota (**Valiela 1995**). Once introduced, exotic species may encounter few (if any) natural pathogens, predators, or competitors in their new environment.

The non-native plant *Hydrilla verticillata* is the #1 aquatic weed in Florida. Native to Asia, hydrilla was likely introduced to Florida in the 1950s (**Simberloff, et al. 1997**) and has spread through the Lower St. Johns River Basin since at least 1967 (**USGS 2015b**). Even the smallest fragment of hydrilla can rapidly grow and reproduce into dense canopies, which are poor habitat for fish and other wildlife. Hydrilla is a superb competitor with native species by monopolizing resources and growing throughout months of lower light (**Gordon 1998**). Huge masses of hydrilla slow water flow, obstruct waterways, reduce native biodiversity, and create stagnant areas ideal for the breeding of mosquitoes (**McCann, et al. 1996**).

Eutrophic conditions due to excessive nitrate conditions can contribute to proliferation of *H. verticillata* in historically oligotrophic waters (**Kennedy, et al. 2009**). In an aquaria experiment with low and high nitrate treatments (0.2 and 1.0 mg nitrate per L, respectively), *H. verticillata* more than doubled its weight in the high nitrate treatment (547 g dry weight) as compared to the low nitrate treatment (199 g dry weight). By comparison, the native species *Sagittaria kurziana* and *Vallisneria americana* did not have a significant difference in weight despite the addition of nitrates. This study suggests that *H. verticillata* will outgrow native aquatic plants as nitrates continue to increase (**Kennedy, et al. 2009**).

A number of non-native herbivorous fish are altering native ecosystems in the Lower St. Johns River. Many of these fish are common in the aquarium trade and include the Eurasian goldfish (*Carassius auratus*; can becomes brown in the wild), Mozambique tilapia *(Oreochromis mossambicus)*, African blue tilapia *(Oreochromis aureus)*, South American brown hoplo *(Hoplosternum littorale)*, and a number of unidentified African cichlids *(Cichlidae spp.)* (**Brodie 2008**; **USGS 2015b**). Additionally, several species of South American algae-eating catfish commonly known in the aquarium trade as "plecos," including the suckermouth catfish *(Hypostomus sp.)* and vermiculated sailfin catfish *(Pterygoplichthys disjunctivus)* appear to be established in the Lower St. Johns River (**USGS 2015b**). As most aquarium enthusiasts know, "plecos" are extremely efficient algae eaters, and, when released into the wild, can have profound impacts on the native community of aquatic plants and animals.

Urbanization can contribute to the altering of flow regimes and water quality in the LSJRB (**Chadwick, et al. 2012**) that may enable invasive organisms to survive. As compared to rural streams where the flow is typically intermittent, urban streams may have perennial flow due to irrigation, leaky sewage tanks and perhaps storm water that was not diverted to retention ponds. The invasive clam *Corbicula fluminea* contributes significant biomass in two urban perennial streams (**Chadwick, et al. 2012**). *Rangia cuneata* was also common on silt-sand substrates near Sixmile Creek and northward in the main river channel to near Cedar River (Mason 1998). Sixmile Creek has a history of low oxygen and fecal coliform problems (**SRR 2012**).

4.5.2.2. Human Health Concerns

Non-native aquatic species can negatively affect human health. Some non-native microorganisms, such as blue-green algae and dinoflagellates, produce toxins that cause varying degrees of irritation and illness in people (**Hallegraeff, et al. 1990**; **Hallegraeff and Bolch 1991**; **Stewart, et al. 2006**). During the summer of 2005, large rafts of toxic algal scum from Lake George to the mouth of the St. Johns River in Mayport, Florida, brought headline attention to toxic bloom-forming algae. The organisms responsible for this bloom were two toxin-producing cyanobacteria (blue-green algae) species: the cosmopolitan *Microcystis aeruginosa* and the non-native *Cylindrospermopsis raciborskii* (**Burns Jr 2008**). *C. raciborskii* has been recorded throughout tropical waters globally, but appears to be expanding into temperate zones as well throughout the U.S. and the world (**Kling 2004**; **Jones and Sauter 2005**). *Cylindrospermopsis* may have been present in Florida since the 1970s, however its presence in the St. Johns River Basin was not noted prior to 1994 (**Chapman and Schelske 1997**; **Phlips, et al. 2002**; **SJRWMD 2005**). Genetic studies reveal strong similarities between populations in Florida and Brazil, suggesting the two populations continually mix or came from the same source relatively recently (**Dyble, et al. 2002**).

Cylindrospermopsis now appears to bloom annually each summer in the St. Johns River with occasionally very high concentrations in excess of 30,000 cells/mL (**Phlips, et al. 2002**). During the intense bloom of 2005, the Florida Department of Health released a human health alert recommending that people avoid contact with waters of the St. Johns River, because the toxins can cause "irritation of the skin, eyes, nose and throat and inflammation in the respiratory tract" (**FDOH 2005**). This public health concern will likely continue to menace the Lower St. Johns River Basin in the foreseeable future, particularly when the water becomes warm, still, and nutrient-rich: conditions favorable to the formation of algal blooms.

4.5.2.3. Social Concerns

In general, many non-native species reproduce so successfully in their environment, that they create unsightly masses that negatively impact recreation and tourism. Such unsightly masses, as those created by water hyacinth *(Eichhornia crassipes)* or hydrilla *(Hydrilla verticillata)*, also shift the way we view and appreciate the aesthetic, intrinsic qualities of our aquatic ecosystems.

4.5.1.1. Economic Concerns

Excessive fouling by successful non-native species can lead to economic losses to industries. In 1986, the South American charrua mussel (*Mytella charruana)* caused extensive fouling at Jacksonville Electric Authority's Northside Generating Station on Blount Island, Jacksonville, Florida (**Lee 2012b**). The charrua mussel probably hitchhiked to the St. Johns River in the ballast water of a ship from South America and continues to persist in the area as evidenced by collections from Mayport, Marineland, and the Arlington area of Jacksonville as recently as 2008 (**Frank and Lee 2008**). Other non-native fouling organisms identified in the St. Johns River include the Asian clam *(Corbicula fluminea),* Indo-Pacific green mussel *(Perna viridis),* and Indo-Pacific striped barnacle *(Balanus amphitrite).* Cleaning these fouling organisms from docks, bridges, hulls of boats and ships, and industrial water intake/discharge pipes is time-consuming and extremely costly.

Non-native species can be serious nuisances on a small scale. They foul recreational boats, docks, sunken ships, and sites of historical and cultural value. Clean-up and control of aquatic pests, such as the floating plant water hyacinth *(Eichhornia crassipes)*, can have high economic costs to citizens, not only in taxpayer dollars, but in out-of-pocket money as well.

4.5.3. Data Sources

Numerous online databases containing non-native species reports were queried. The most comprehensive listing of species is maintained in the Nonindigenous Aquatic Species (NAS) database of the United States Geological Service. Resources to investigate distributions of non-native plants include EDDMAPS, USDA, and the Atlas of Florida Vascular Plants. Additional records and information were obtained from agency reports, books, published port surveys, and personal communication data.

4.5.4. Limitations

We expect that many more non-native species are found within the LSJRB, but have not been recognized or recorded, either because they are *naturalized*, *cryptogenic,* or lack of the taxonomic expertise to identify foreign species, subspecies, or hybrids.

*A naturalized species is any non-native species that has adapted and grows or multiplies as if native (**Horak 1995**).*

*A cryptogenic species is an organism whose status as introduced or native is not known (**Carlton 1987**).*

4.5.5. Current Status

Approximately 74 non-native aquatic species are documented in the LSJRB (Table 4.9). Non-native species recorded in the LSJRB include floating or submerged aquatic plants, molluscs, fish, crustaceans, amphibians, jellyfish, mammals, reptiles, tunicates, bryozoans, and blue-green algae (Table 4.9). Freshwater species represent > 65% of the species introduced into the LSJRB. Non-native aquatic species originate from the Central and South America, the Caribbean, Asia, and Africa (Table 4.9).

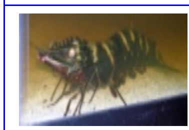
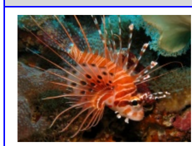
Given the devastating impacts of lionfish on coastal communities, Florida Fish and Wildlife Conservation Commission have waived the recreational license requirement if using designated spearing devices and have also waived bag limits for harvesting lionfish (**FWC 2014d**). To date, lionfish have only been recorded off shore of northeast Florida and not in the SJR.

Other species raising concern is the Muscovy duck that can transmit disease to and can interbreed with Florida's native waterfowl (**FWC 2014b**). In addition, the black and white tegu has been observed in Avondale and have the potential to enter gopher tortoise holes for mice and tortoise eggs (**CISEH 2014; JHS 2014**).

Table 4.9 Non-native aquatic species recorded in the Lower St. Johns River Basin

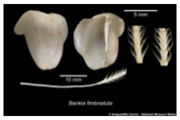
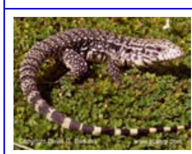
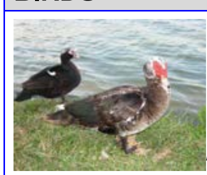
LIFEFORM	COMMON NAME	SCIENTIFIC NAME	HABITAT REALM	DATE	ORIGIN	PROBABLE VECTORS	COUNTY- FIRST REPORTED	REF
AMPHIBIANS								
	Cane toad *Photo: USGS NAS*	*Rhinella marina*	Freshwater, Brackish	Intentionally introduced to several locations in South Florida between 1936 and 1958.	South and Central America	Humans, range expansion from South Florida populations	Collected: Clay, 1987	**USGS 2015b**
	Cuban treefrog *Photo: USGS NAS*	*Osteopilus septentrionalis*	Terrestrial, Freshwater (springs, lakes, ponds)	First detected in Key West before 1928. Spread northward through Keys. Now recorded in southern half of Florida.	Caribbean	Dispersing northward from S. Florida populations, floating vegetation/debris, humans, vehicles, bulk freight/cargo, plant or parts of plants	Established: Duval, 2002 Collected: Clay, 1991	**CISEH 2014; USGS 2015b**
TUNICATES								
	Pleated (or rough) sea squirt *Photo: SERTC/SC DNR*	*Styela plicata*	Marine	Unknown; Reported offshore Jacksonville as early as 1940.	Indo-Pacific? This species is now found in tropical and warm-temperate oceans around the world.	Ship/boat hull fouling, ship ballast water/sediment, importation of mollusk cultures		**De Barros, et al. 2009; GBIF 2012a**
ECTOPROCTS - BRYOZOANS								
	Brown bryozoan	*Bugula neritina*	Marine, Brackish	Beaufort, NC (1878 record); Dry Tortugas (1900 record); widespread in SE Atlantic by mid-1900's.	Native range is unknown - probably Mediterranean Sea (1758 record).	Ship/boat hull fouling		**Eldredge and Smith 2001; NEMESIS 2014**
		Celleporaria pilaefera	Marine	2001	Indo-Pacific	Ship/boat hull fouling, aquaculture	SJR, Jacksonville	**McCann, et al. 2007; NEMESIS 2014**
		Arbopercula bengalensis	Marine	2001	India and tropical, subtropical coast of China		SJR, Jacksonville	**McCann, et al. 2007; NEMESIS 2014**
		Hippoporina indica	Marine	2001	Western Pacific	Ship/boat hull fouling	SJR, Jacksonville	**McCann, et al. 2007; NEMESIS 2014**
		Sinoflustra annae	Marine	2001	Indo-Pacific		SJR, Jacksonville	**McCann, et al. 2007; NEMESIS 2014**
POLYCHAETE								
		*Ficopomatus uschakovi*	Marine	1997: East and Gulf coast	Indo-Pacific	Ship/boat hull fouling, ballast water	Established: 2002, SJR, Jacksonville	**NEMESIS 2014**

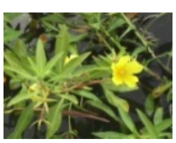
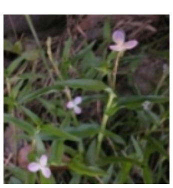
LIFEFORM	COMMON NAME	SCIENTIFIC NAME	HABITAT REALM	DATE	ORIGIN	PROBABLE VECTORS	COUNTY- FIRST REPORTED	REF
		*Hydroides diramphus*	Marine	1970: Key West	Western Atlantic and/or Indo-Pacific	Ship/boat hull fouling, ballast water	2002, Mayport	**NEMESIS 2014**
JELLYFISH								
	Freshwater jellyfish *Photo: USGS NAS*	*Craspedacusta sowerbyi*	Freshwater (ponds, lake)	First described in Philadelphia in 1928. Recorded throughout the US. Most common in temperate states in eastern US	Asia	Aquaculture stock, other live animal, plant or parts of plants	Collected: Duval, 1999; Putnam, 1999	**USGS 2015b**
CRUSTACEANS								
	Bocourt swimming crab *Photo: Big Bend Brian*	*Callinectes bocourti*	Marine, Brackish	First US report was Biscayne Bay, FL, 1950.	Caribbean and South America	From the Caribbean via major eddies in Gulf Stream or southern storm events	Collected: Duval 2002	**USGS 2015b**
	Indo-Pacific swimming crab *Photo: SC DNR*	*Charybdis hellerii*	Marine-offshore	First US report was South Carolina (1986), Indian River Lagoon, FL (1995)	Indo-Pacific	Ship ballast water/sediment, or drift of juveniles from Cuba		**USGS 2015b**
	Green porcelain crab *Photo: D. Knott*	*Petrolisthes armatus*	Marine, Brackish	Indian River Lagoon, FL (1977), Georgia (1994), and SC (1995)	Caribbean and South America	Natural range expansion, ship ballast water/sediment, importation of mollusk cultures		**Power, et al. 2006**
	Slender mud tube-builder amphipod *Photo: VIMS*	*Corophium lacustre*	Freshwater, Brackish	First record in the St. Johns River in 1998.	Europe and Africa	Ship ballast water/sediment from Europe		**GBIF 2012c; Power, et al. 2006**
	Skeleton shrimp *Photo: D. Knott*	*Caprella scaura*	Marine	Caribbean Sea (1968), St. Johns River (2001)	Indian Ocean	Ship/boat hull fouling, ship ballast water/sediment		**Foster, et al. 2004; GBIF 2012d**
	Asian tiger shrimp *Photo: David Scott SERTC*	*Penaeus monodon*	Marine	SC, GA, FL 1998	East Africa, South Asia, Southeast Asia, the Philippines, and Australia	Accidental release	Established: Duval, 2008; Putnam, 2013	**USGS 2015b**
	Wharf roach *Photo: Ruppert and Fox (1998)*	*Ligia exotica*	Marine	Unknown	Northeast Atlantic and Mediterranean Basin	Bulk freight/cargo, ship ballast water/sediment, shipping material from Europe		**Power, et al. 2006**

LIFEFORM	COMMON NAME	SCIENTIFIC NAME	HABITAT REALM	DATE	ORIGIN	PROBABLE VECTORS	COUNTY- FIRST REPORTED	REF
	Striped barnacle *Photo: A. Cohen*	*Balanus amphitrite*	Marine	Unknown	Indo-Pacific	Ship/boat hull fouling		**Power, et al. 2006**
	Triangular barnacle *Photo: D. Elford*	*Balanus trigonus*	Marine	Unknown	Indo-Pacific	Ship/boat hull fouling		**GSMFC 2010**
	Barnacle *Photo: C. Baike*	*Balanus reticulatus*	Marine	Unknown	Indo-Pacific	Ship/boat hull fouling		**GSMFC 2010**
	Titan acorn barnacle *Photo: H. McCarthy*	*Megabalanus coccopoma*	Marine	First recorded in Duval Co, FL - 2004; Common by 2006.	Pacific Ocean	Ship/boat hull fouling	Duval: 2004; Mayport 2008	**Frank and Lee 2008**
	Mediterranean acorn barnacle *Photo: H. McCarthy*	*Megabalanus antillensis* (also known as *M. tintinnabulum)*	Marine	Unknown	Europe (Mediterranean Sea)	Ship/boat hull fouling		**Masterson 2007; McCarthy 2011**
	Asian tiger shrimp *Photo: M. Watkins, FWRI-Jacksonville*	*Penaeus monodon*	Marine, Brackish	First recorded in Duval Co, FL – 2008.	Australasia	Aquaculture stock	Duval 2008; St. Johns 2011; Volusia 2010	**CISEH 2014; USGS 2015b**
FISH								
	Lionfish *Photo: A. Baeza*	*Primarily Pterois volitans (red lionfish) with a small number of Pterois miles (devil firefish)*	Marine-offshore	First U.S. reports were Dania, FL (1985) and Biscayne Bay (1992). Offshore Jacksonville (2001).	Indo-Pacific	Humans: aquarium releases or escapes		**USGS 2015b**
	Goldfish *Photo: USGS NAS*	*Carassius auratus*	Freshwater	Intentional releases in the US, late 1600's.	Eurasia	Intentional release, ornamental purposes, stocking, aquarium trade, escape from confinement, landscape/fauna "improvement"	Reported: Putnam 1974	**USGS 2015b**
	Unidentified cichlids *Photo: USGS NAS*	*Cichlidae spp.*	Freshwater	Recorded in LSJRB between 2001 and 2006.	Africa	Humans		**GSMFC 2010**; **Brodie 2008**; **USGS 2015b**
	Blue tilapia *Photo: USGS NAS*	*Oreochromis aureus*	Freshwater (pond, lake)	In 1961, 3,000 fish stocked in Hillsborough Co, FL. Recorded in LSJRB between 2001 and 2006.	Europe and Africa	Humans: intentional fish stocking	Established: Duval 1984; Putnam 2010	**GSMFC 2010**; **Brodie 2008**; **USGS 2015b**

LIFEFORM	COMMON NAME	SCIENTIFIC NAME	HABITAT REALM	DATE	ORIGIN	PROBABLE VECTORS	COUNTY- FIRST REPORTED	REF
	Mozambique tilapia *Photo: USGS NAS*	*Oreochromis mossambicus*	Freshwater, Brackish	1960's - Introduced/established in Dade Co, FL. Recorded in LSJRB between 2001 and 2006.	Africa	Humans: stocked, intentionally released, escapes from fish farms, aquarium releases		**GSMFC 2010**; **Brodie 2008**; **USGS 2015b**
	Unidentified tilapia *Photo: USGS NAS*	*Tilapia spp.*	Freshwater (pond)	Recorded in LSJRB between 2001 and 2006.	Africa	Humans		**GSMFC 2010**; **Brodie 2008**
	Unidentified Pacu *Photo: USGS NAS*	*Colossoma or Piaractus sp.*	Freshwater, Brackish (tributary, creek)	1984-1989	South America	Aquaculture stock (fish farm escapes or releases), humans (aquarium releases)	Report: Duval 1989	**USGS 2015b**
	Brown Hoplo *Photo: USGS NAS*	*Hoplosternum littorale*	Freshwater	First recorded in Indian River Lagoon, 1995.	South America	Humans	Report: Duval 2008; Established: Duval 2005	**USGS 2015b**
	Wiper (Hybrid Striped Bass) (Whiterock = *female striped bass x male white bass*, Sunshine Bass = *male striped bass x female white bass*) *Photo: T. Pettengill*	*Morone chrysops x saxatilis (Artificial hybrid between the white bass and the striped bass)*	Freshwater (pond, lake), Brackish, Marine	Intentionally stocked in the 1970's. Identified in 1992.	Artificial Hybrid	Humans: intentional fish stocking	Stocked: Duval and Clay 1992	**USGS 2015b**
	Unidentified armored catfish *Photo: USGS NAS*	*Loricariidae spp.*	Freshwater	Recorded in LSJRB between 2001 and 2006.	South and Central America	Aquaculture stock (fish farm escapes or releases), humans (aquarium releases)		**FWRI 2006**; **Brodie 2008**
	Suckermouth catfish *Photo: L. Smith*	*Hypostomus sp.*	Freshwater	1974, 2003	South and Central America	Aquaculture stock (fish farm escapes or releases), humans (aquarium releases)		**USGS 2015b**
	Southern sailfin catfish *Photo: K.S. Cummings*	*Pterygoplichthys anisitsi*	Freshwater (river)	2007	South America	Humans: likely aquarium release	Established: St. Johns 2007	**USGS 2015b**
	Vermiculated sailfin catfish *Photo: USGS NAS*	*Pterygoplichthys disjunctivus*	Freshwater (river)	2003	South America	Aquaculture stock (fish farm escapes or releases), humans (aquarium releases)	Established: Putnam 2003	**USGS 2015b**
	Redtail catfish *Photo: Monika Betley commons.wikimedia.or*	*Phractocephalus hemioliopterus*	Freshwater, Brackish	2007	Tropical America	Humans (aquarium releases)	Reported: Clay 2014	**News4JAX 2015; USGS 2015b**
MAMMALS								
	Nutria *Photo: USGS NAS*	*Myocaster coypus*	Freshwater (retention pond, drainage ditch), Terrestrial	1956, 1957, 1963 Introduced into Florida for fur farming.	South America	Humans: escaped or released from captivity	Established: Duval 1963	**CISEH 2014; USGS 2015b**

LIFEFORM	COMMON NAME	SCIENTIFIC NAME	HABITAT REALM	DATE	ORIGIN	PROBABLE VECTORS	COUNTY- FIRST REPORTED	REF
MOLLUSCS								
	Asian clam *Photo: USGS NAS*	*Corbicula fluminea*	Freshwater (stream, lake)	Florida in 1964; 1990- Volusia County; 1975- Lake Oklawaha; 1974-76 Black Creek	Asia and Africa	Humans, live seafood, bait, aquaculture stock, water	Established: Duval 2003; Volusia 1990	**CISEH 2014; Frank and Lee 2008; Lee 2008; USGS 2015b**
	Charrua mussel *Photo: H. McCarthy*	*Mytella charruana*	Marine	1986- Jacksonville; 2004- Mosquito Lagoon; 2006- Mayport (Duval Co), 2006- Marineland (Flagler Co)	South America	Ship ballast water/sediment	Duval 1986; Flagler 2006	**Boudreaux and Walters 2006; CISEH 2014; Frank and Lee 2008; Power, et al. 2006; Spinuzzi, et al. 2012; USGS 2015b**
	Green mussel *Photo: H. McCarthy*	*Perna viridis*	Marine, Brackish (river)	1999- Tampa Bay; 2003- St. Augustine and Jacksonville	Indo-Pacific	Ship ballast water/sediment, ship/boat hull fouling, humans		**Frank and Lee 2008; Power, et al. 2006; Spinuzzi, et al. 2012**
	Paper pondshell *Photo: B. Frank*	*Utterbackia imbecillis*	Freshwater (lake)	Lake Oneida, UNF (Duval Co, FL) 2005, Recorded in 1990 in Sawgrass area	North America: Native in Mississippi River and Great Lakes	Other live animal, plant or parts of plants, ship/boat		**Frank and Lee 2008; Lee 2008**
	Red-rim melania *Photo: B. Frank*	*Melanoides tuberculata*	Freshwater (river)	1976- Willowbranch Creek, Riverside, Jacksonville, FL	Asia and Africa	Other live animal, plant or parts of plants, ship/boat	Established: Duval 1976	**CISEH 2014; Frank and Lee 2008; Lee 2008; USGS 2015b**
	Fawn melania *Photo: B. Frank*	*Melanoides cf. turricula*	Freshwater	Fruit Cove (St. Johns Co, FL) 2006; Arlington area of Jacksonville (Duval Co, FL) 2006	North America: Native in western US and Canada	Other live animal, plant or parts of plants, ship/boat		**Frank and Lee 2008**
	Spiketop applesnail *Photo: B. Frank*	*Pomacea diffusa*	Freshwater (pond, drainage ditch)	2006	South America	Humans: probable aquarium releases	Duval 2006; Clay 2011	**CISEH 2014; Frank 2008; Rawlings, et al. 2007**
	Channeled applesnail *Photo: Georgia DNR*	*Pomacea canaliculata*	Freshwater (retention pond)	Unknown	South America	Humans: probable aquarium releases	Established: Duval 2006	**CISEH 2014; Frank 2008; Rawlings, et al. 2007; USGS 2015b**
	Island applesnail *Photo: B. Frank*	*Pomacea (maculatum) insularum*	Freshwater (lake, creek, drainage ditch, river)	Unknown	South America	Humans: probable aquarium releases	Duval 2005; St. Johns 2005; Volusia 2005	**CISEH 2014; Frank 2008; Rawlings, et al. 2007; USGS 2015b**
	Mouse-ear marshsnail *Photo: B. Frank*	*Myosotella myosotis*	Marine	Unknown	Europe	Bulk freight/cargo, ship ballast water/sediment,		**Frank and Lee 2008**

LIFEFORM	COMMON NAME	SCIENTIFIC NAME	HABITAT REALM	DATE	ORIGIN	PROBABLE VECTORS	COUNTY- FIRST REPORTED	REF
	Striped falselimpet *Photo: B. Frank*	*Siphonaria pectinata*	Marine (Mayport), Brackish (Sister's Creek)	Unknown	Europe and Africa (Mediterranean Sea)	Bulk freight/cargo, ship ballast water/sediment, ship/boat hull fouling, humans	Duval 2008; Mayport 2011	**Frank and Lee 2008**; **McCarthy 2008**
	Fimbriate shipworm *Photo: A. Cymru (Nat'l Museum of Wales)*	*Bankia fimbriatula*	Marine	Unknown	Pacific?	Ship/boat hull fouling, humans		**Frank and Lee 2008**
	Striate Piddock shipworm *Photo: J. Wooster*	*Martesia striata*	Marine	Unknown	Indo-Pacific?	Ship/boat hull fouling, humans		**Frank and Lee 2008**
	Gulf Wedge Clam *Photo: B. Frank*	*Rangia cuneata*	Brackish	Present in Atlantic east coast Pleistocene deposits; First live Atlantic record in 1946.	Prior to 1946, native range was considered Gulf Coast of northern FL to TX.	Possible vectors: transplanted seed oysters, oyster shipments, ballast water		**Carlton 1992; Carlton 2012; Foltz, et al. 1995; GBIF 2012b; Lee 2012a; NEMESIS 2014; Verween, et al. 2006**
REPTILES								
	Red-eared slider *Photo: USGS NAS*	*Trachemys scripta elegans*	Freshwater (drainage ditch), Brackish	Unknown	North America: US midwestern states to northeastern Mexico	Humans: pet releases and escapes	Collected: Duval 1991 1999 Established: Clay 2012	**CISEH 2014; USGS 2015b**
	Razorback Musk Turtle *Photo: R.C. Thomson*	*Sternotherus carinatus*	Freshwater (drainage ditch) Brackish	1958 specimen collected Putnam Co.; 2008 first verified voucher specimen recorded in Florida	Native to 6 states: statewide in LA, southern MS, southern AR, southeastern OK, eastern TX, small portion of southwestern AL	Humans: pet releases and escapes	Established: Putnam 1958	**Krysko, et al. 2011; Lindeman 2008; USGS 2015b**
	Black and white tegu	*Tupinambis merianae*					Duval 2013	**JHS 2014**
BIRDS								
	Muscovy duck *Photo: FWC*	*Cairina moschata*	Freshwater	1967	Central and South America	Humans: pet releases and escapes	Clay 1986; Duval 1991; Flagler 1991; Putnam 1991; St. Johns 1991; Volusia 1991	**CISEH 2014; FWC 2014b**
AQUATIC PLANTS								
	Alligator-weed *Photo: USGS NAS*	*Alternanthera philoxeroides*	Freshwater	1887-1894 in Florida, 1982-1992 specimens collected	South America	Ship ballast water/sediment	Duval 2004; Putnam 2002; St. Johns 2004; Clay 2008Flagler 2003	**CISEH 2014; McCann, et al. 1996; USDA 2013; USGS 2015b**

LIFEFORM	COMMON NAME	SCIENTIFIC NAME	HABITAT REALM	DATE	ORIGIN	PROBABLE VECTORS	COUNTY- FIRST REPORTED	REF
	Para grass *Photo: F. & K. Starr*	*Urochloa (Brachiaria) mutica*	Freshwater	1982-1992	Africa	Humans: intentional release for agriculture	Putnam, Volusia	**FCCDR 2008; McCann, et al. 1996; USGS 2015b**
	Water spangles *Photo: IFAS Univ. of Florida*	*Salvinia minima*	Freshwater (lakes, ponds)	1928 - First report for North America in and along St. Johns River; 2003 - expanding range	South and Central America	Ship ballast water/sediment, humans, aquarium trade	St. Johns 1930; Putnam 1973; Flagler 1983	**CISEH 2014; McCann, et al. 1996; USGS 2015b**
	Hydrilla *Photo: USGS NAS*	*Hydrilla verticillata*	Freshwater (lake, creek, river)	1967-1994 (USGS), early 1950s (Simberloff *et al.*)	Asia	Debris associated with human activities, ship/boat, aquarium trade, garden waste disposal	Duval 1997; Clay 1995; Flagler 2010; Putnam 1969; St. Johns 1967; Volusia 2007	**CISEH 2014; McCann, et al. 1996; USGS 2015b**
	Water-hyacinth *Photo: USGS NAS*	*Eichhornia crassipes*	Freshwater (pond, lake, ditch, canal, river)	First released 1880's, 1990-1994	South America	Humans, aquarium trade, garden escape	Duval 2009; St. Johns 2009; Clay 1900; Putnam 1972; Flagler 2003; Volusia 1963	**CISEH 2014; McCann, et al. 1996; USGS 2015b**
	Water-lettuce *Photo: USGS NAS*	*Pistia stratiotes*	Freshwater	Described in Florida in 1765 (Bartram 1942)	South America	Ship ballast water/sediment	Duval, Putnam, Volusia	**FCCDR 2008; McCann, et al. 1996; USGS 2015b**
	Brazilian waterweed *Photo: USGS NAS*	*Egeria densa*	Freshwater	1969-1995, First record at St. Johns River at Cross Florida Barge Canal (1969)	South America	Humans: accidental aquarium releases, intentional release for control of mosquito larvae	Duval 1995; Putnam, 1969; Volusia	**CISEH 2014; FCCDR 2008; McCann, et al. 1996; USGS 2015b**
	Water sprite *Photo: A. Murray*	*Ceratopteris thalictroides*	Freshwater	1984-1992 specimens collected	Australasia	Humans	Volusia	**FCCDR 2008; McCann, et al. 1996; USGS 2015b**
	Wild taro *Photo: K. Dressler*	*Colossian esculenta*	Freshwater (ditch, stream, lakeside, floodplain swamp, baygall)	Introduced to FL by Dept of Agriculture in 1910; 1971-1992 specimens collected	Africa	Humans	Duval 2006; Clay 1985; Putnam 1995; Flagler 2006; St. Johns 2009; Volusia 2005	**CISEH 2014; McCann, et al. 1996; USGS 2015b**
	Uruguay water-primrose *Photo: Washington State Noxious Weed Control Board*	*Ludwigia uruguayensis*	Freshwater	1998 specimen collected	South America	Humans	Clay 1998; Alachua	**CISEH 2014; McCann, et al. 1996; USGS 2015b**
	Marsh dewflower *Photo: L. Lee*	*Murdannia keisak*	Freshwater	1960 specimen collected	Asia	Humans	Duval 1960	**CISEH 2014; USGS 2015b**

LIFEFORM	COMMON NAME	SCIENTIFIC NAME	HABITAT REALM	DATE	ORIGIN	PROBABLE VECTORS	COUNTY- FIRST REPORTED	REF
	Parrot-feather *Photo: USGS NAS*	*Myriophyllum aquaticum*	Freshwater (slough)	1940-1995 specimens collected	South America	Humans	Clay 1940; St. Johns, Flagler 1940; Volusia 2005	**CISEH 2014; FCCDR 2008; McCann, et al. 1996; USGS 2015b**
	Brittle naiad *Photo: USGS NAS*	*Najas minor*	Freshwater (lake)	1983-1984 specimens collected, in US since 1930's	Eurasia	Humans	Putnam 2002	**CISEH 2014; FCCDR 2008; McCann, et al. 1996; USGS 2015b**
	Crested floating-heart *Photo: C. Jacono*	*Nymphoides cristata*	Freshwater	2003 specimen collected	Asia	Humans	St. Johns	**FCCDR 2008; USGS 2015b**
	Water-cress *Photo: WI DNR*	*Nasturtium officinale*	Freshwater	1995 specimens collected	Eurasia	Humans	Duval 1995; Clay 1995; Putnam 1995; St. Johns	**CISEH 2014; FCCDR 2008; McCann, et al. 1996; USGS 2015b**
	Torpedo grass *Photo: V. Ramey*	*Panicum repens*	Freshwater (adjacent to waterways)	1982-1992 specimens collected, Lower Kississimee Valley 1920s	Europe	Humans	Duval 2004; Clay 2005; Putnam 2002; St. Johns 2003; Volusia 2003; Flagler 2003	**CISEH 2014; FCCDR 2008; McCann, et al. 1996; USGS 2015b**
BLUE-GREEN ALGAE								
	Blue-green alga *Photo: Umwelt Bundes Amt*	*Cylindrospermopsis raciborskii*	Freshwater	1950's first ID in the US; 1995 first ID in Florida	South America (High degree of genetic similarity with specimens from Brazil)	Humans, other live animal (digestion/ excretion), aquarium trade, ship ballast water/sediment, ship/boat, water (interconnected waterways)		**Dyble, et al. 2002**

4.5.2. Trend

The cumulative number of non-native aquatic species introduced into the LSJRB has been increasing at an exponential rate since records were kept prior to 1900 (Figure 4.30). This trend is the reason that the category is assigned a CONDITIONS WORSENING status – indicating that non-native species are contributing to a declining status in the health of the St. Johns River Lower Basin. For this reason the current status has been assigned as *unsatisfactory*.

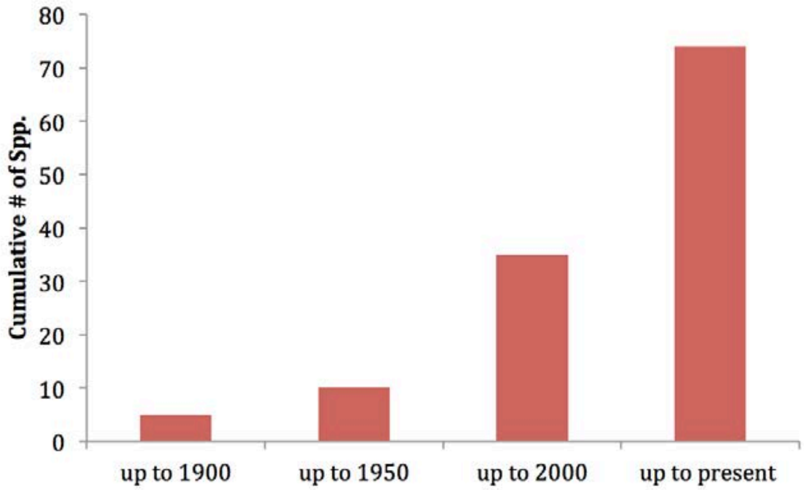


Figure 4.30 Cumulative Number of Non-native Aquatic Species Introduced into the Lower St. Johns River Basin, Florida since the turn of the 20th century.

Non-native plants and animals arrive in the St. Johns River watershed by various means. Common vectors of transport have been humans, ship ballast consisting of water and/or sediment, ship/boat hull fouling, and mariculture/aquaculture activities (Table 4.4). One of the most widespread ways that non-native species arrive in Florida is when people accidentally or intentionally release exotic aquarium plants or pets into the wild. Recently two boys caught a predatory redtail catfish in Clay County from a local pond (**News4JAX 2015**). The aquarium fish was likely released and can reach 80 kg in weight (**News4JAX 2015; USGS 2015b**). Such releases not only violate state and federal laws but can have devastating impacts on native ecosystems and native biodiversity.

4.5.3. Future Outlook

IRREVERSIBLE IMPACTS. Once a non-native species becomes naturalized in a new ecosystem, the environmental and economic costs of eradication are usually prohibitive (**Elton 1958**). Thus, once an invasive species gets here, it is here to stay, and the associated management costs will be passed on to future generations. Since the early 1900s, taxpayer dollars have been paying for ongoing efforts to control the spread of invasive non-native aquatic species in the St. Johns River.

Case Study: Water Hyacinth and the future of biological controls for invasive plant species. One of the most, *if not the most*, notorious and devastating introductions of a non-native species into the St. Johns River is the lovely South American aquatic plant known as the water hyacinth. Water hyacinth was introduced into the river in 1884 near Palatka. By 1896, it had spread throughout most of the LSJRB and was already hindering steamboat navigation. Water hyacinth causes changes in water quality and biotic communities by severely curtailing oxygen and light diffusion and reducing water movement by 40 to 95% (**McCann, et al. 1996**). If growth remains unchecked, these non-native aquatic plants form dense mats that obstruct waterways, disrupt transportation, and modify natural hydrology patterns and native communities and biodiversity.

The U.S. Army Corps of Engineers (USACE) periodically sprays herbicides on the St. Johns River to control the growth of this weedy invader. From 2001 to 2006, the USACE sprayed an average of 3,042 gallons of herbicide annually on about 5,102 acres of the St. Johns River and its tributaries. This represents an average of 608 acres in the Lower Basin that were treated with herbicides during this time period (**USACE 2012**). It is likely that the use of herbicides to control invasive aquatic plants will continue into the future with negative impacts on the health of the St. Johns River watershed. The financial and ecological impacts will be multiplied, if additional invasive species become a public nuisance requiring periodic control.

The negative impacts of hydrilla have been so pervasive and intense in Florida, that U.S. scientists have experimentally released four biological control insects from Pakistan that feed on hydrilla in its native habitat and have also stocked infested Florida lakes with non-reproducing Chinese grass carp (*Ctenopharyngodon idella*), which preferentially eat hydrilla (**Richard and Moss 2011**). Of the three non-native apple snails in the LSJRB, *Pomacea insularum* feeds upon *H. verticillata* but also a range of native aquatic plants, and thus cannot serve as a reliable biological control (**Baker, et al. 2010**). In addition another non-native species *Myriophyllum aquaticum* was not eaten by the snail (**Baker, et al. 2010**). The mottled water hyacinth weevil (*Neochetina eichhorniae*), the chevroned water hyacinth weevil (*N. bruchi*) and the water hyacinth planthopper (*Megamalus scutellaris*) also show promise (**IFAS 2013**). Introducing exotics to control exotics, of course, can produce a secondary layer of ecological problems and unforeseen implications.

HIGH RISK. There is a high probability that future invasions of non-native aquatic species will continue to occur in the LSJRB. Human population in northeast Florida is projected to more than double by 2060 (**Zwick and Carr 2006**). The number of ships visiting the Port of Jacksonville has increased since 2002 (Figure 4.31) and is expected to increase further with weekly cargo vessel calls by CKYH (Cosco, "K" Line, Yang Ming and Hanjin), calls by G6 Alliance shipping lines (APL, Hapag-Lloyd, Hyundai Merchant Marine, Mitsui O.S.K. Lines, Nippon Yusen Kaisha and Orient Overseas Container Line), and an increasing number of cruise ship visits (**JAXPORT 2015**). In December 2014, America Honda Export announced that it will use the port to export Acura models to Kuwait and elsewhere in the Middle East (**JOC 2014**). In January 2015, the largest container ship of 1,036 ft. in length docked in the port (**JAXUSA 2015**). Significant vectors for transporting non-native organisms were humans and ship ballast (Table 4.4), and both of these vectors are expected to contribute to the likelihood for additional and potentially more frequent introductions.

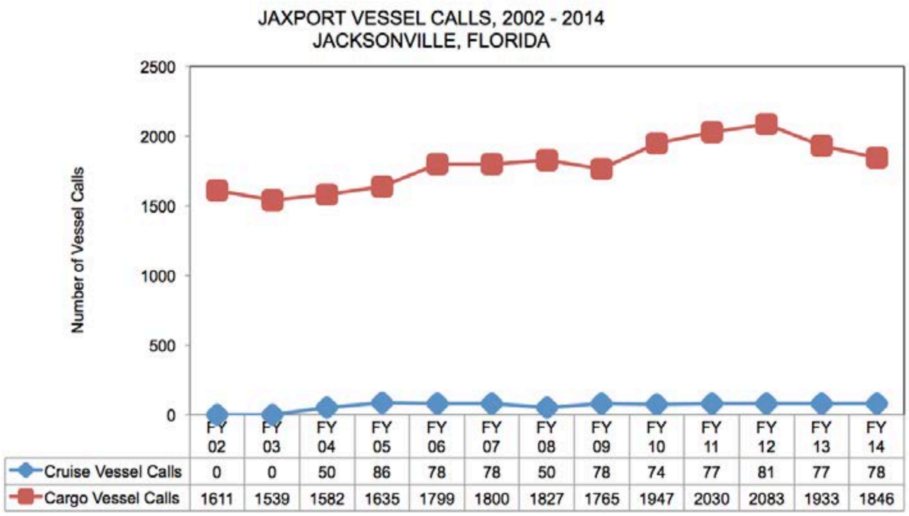


*Figure 4.31 Number of Cruise Ships and Cargo Ships Calling on Port of Jacksonville, FL (JaxPort) Terminals between Fiscal Year 2002 and 2014. Fiscal year (FY) begins Oct 1 (**JAXPORT 2015**).*

Additional invasions into the Lower St. Johns River Basin are expected from adjacent or interconnected water bodies. For example, 19 non-native aquatic species not found in the LSJRB have been recorded in the Upper St. Johns River Drainage Basin (**USGS 2015b**). These species may disperse into the LSJRB. In addition, 85% of living non-native plants that are received into the US come from the Port of Miami (**ELI 2008**). Rising global temperatures may also contribute to a northward expansion in the range of non-native species from Central and South Florida. For example, the old world climbing fern and Cuban treefrog were recorded in St Johns and Duval counties in 2012, species spreading from southern Florida (**CISEH 2014**). There is concern that the Cuban treefrog can spread as tadpoles in fresh and brackish water with ~80% survival at 12 ppt and also able to survive 14 ppt for up to 24 hours (**Johnson and McGarrity 2013**). Gilg, et al. (**Gilg, et al. 2014**) studied dispersal of the green mussel near the Matanzas, St. Augustine, and Ponce de Leon Inlet. Mussel spat density was positively correlated with temperature and likely to be correlated with phytoplankton availability. Larvae settled within 10 km of source population located in the Intracoastal Waterway. The authors suggest that populations at the mouth of the SJR may be connected to the more southern populations via transport along the coast, but that persistence is due to localized recruitment (**Gilg, et al. 2010**).

5. Contaminants

5.1. Background

Contaminants are chemicals that are found at elevated concentrations in any given environment. Some are produced solely by human activity, but many are also produced naturally in small quantities. Both anthropogenic (human-made) and naturally occurring compounds may become contaminants when they are introduced into ecosystems at elevated concentrations, often as a result of human activity (examples are polyaromatic hydrocarbons, or PAHs, and metals). Concentrations of naturally-occurring compounds often vary with local geology and environment. Thus, it is much more difficult to detect human input and harmful concentrations for naturally occurring compounds than for those that are produced solely by human activity.

A chemical becomes environmentally significant when it is prevalent, persistent, and toxic. The prevalence of a chemical in any system depends on how much of it goes in and how quickly it goes out, either by flowing out or by degrading. A compound that is persistent breaks down slowly and is removed slowly. The probability of long-term toxic effects increases with persistence. Some types of chemicals are taken up and stored in fat tissues of plants and animals with little or no degradation, i.e., they ***bioaccumulate***. Bioaccumulated chemicals are stored in tissues of prey organisms and when prey are eaten, the chemicals can be transferred to predators and travel up the food chain in increasingly higher levels, i.e., they ***biomagnify***. Thus, organisms containing the bioaccumulated chemicals act as a reservoir, which is only slowly depleted.

Contaminants can also reside in sediments and in the water. They will partition between biota, sediments and water in ratios that depend on the chemical and the conditions. The sediments of rivers often serve as reservoirs for chemical contaminants. Many of the environmentally important compounds are attracted to the organic matter in sediments and end up there, regardless of how they enter the water body. Plants and animals that live in sediments (benthic organisms) are potentially exposed to contaminated water and sediments, so assessments of their toxic responses to contaminants are particularly important in determining overall river health.

Figure 5.1 Sediment at Talleyrand, LSJR

5.1.1. Assessments of Status and Trends

Chemicals in four environmentally significant categories are evaluated in this report. The categories include 1) polyaromatic hydrocarbons (PAHs), 2) metals, 3) polychlorinated biphenyls (PCBs), and 4) pesticides. These chemicals vary in their chemical structure, their sources, and their specific fates and effects, but they all have a high potential for prevalence, persistence, toxicity and bioaccumulation. Each of the categories is discussed separately.

Sediment concentrations are examined in terms of frequency of occurrence, the concentrations present, and whether any trends up or down exist. The cumulative impact of the chemicals is estimated as well as the relative toxic impact of the different classes in different regions. Methods we used to determine toxic impact are discussed in the next section. It is important to note that most of these data end in 2007.

Water column concentrations of metals is included because more of these compounds will reside in the water column than the other classes of chemicals. The distributions of the metal data are compared to Florida ambient water quality standards. These parameters are regularly monitored and data are current.

The rate at which chemicals are released into the environment clearly affects their potential environmental impact. In addition to examining concentrations of contaminants found in the LSJR sediments and water, we examined the status and trends of reported chemical releases into the atmosphere and waterways of the LSJR using the Toxics Release Inventory database (**EPA 2015c; EPA 2015a**) and the Risk Screening Environmental Indicators model (**EPA 2013c**), both provided by EPA. Releases of all chemicals are discussed in Section 5.4 and releases of the metals and PAHs are discussed in their respective sections.

5.2. Data Sources and Analysis

5.2.1. Water

All data were obtained from the Florida DEP STORET database. STORET is a computerized environmental data system containing water quality, biological, and physical data. Total metal concentrations of the LSJR were used in this analysis. EPA methods 200.7, 200.8, and 206.2 were used to measure arsenic; EPA methods 200.7, 200.8, 213.2, and 6010B were used to measure cadmium; EPA methods 200.7, 200.8, 220.2, and 6010B were used to measure copper; EPA methods 200.7, 200.8, 249.2, and 6010B were used to measure nickel; EPA methods 200.7, 200.8, 272.2, and 6010B were used to measure silver; and EPA methods 200.7, 200.8, and 6010B were used to measure zinc.

The LSJR varies in salinity, with the mainstem predominantly freshwater and some of the tributaries ranging from fresh- to full strength seawater. Salinity may affect the toxicity of some metals to aquatic life therefore the EPA class III Water Quality Criterion (WQC) values may be different for freshwater and marine water. Likewise, for freshwater, hardness, defined as the total concentration of the divalent cations calcium and magnesium, has also been shown to reduce the toxicity of the metals cadmium, copper, lead, nickel, and zinc; therefore the freshwater criterion is based on an equation which incorporates the hardness of the water body. For the hardness dependent metals in this analysis, an average hardness value of 100 mg $CaCO_3$/L was used for generating the freshwater criteria.

The WQC for marine (haline; surface chloride concentration ≥ 1,500 mg/L) waters was also used for all of the metals, except for silver, for which no marine water quality criterion has currently been adopted by the U.S.EPA. Therefore, the current proposed WQC value for silver has been used. It must be pointed out that the freshwater and marine WQC are the same for some metals, like arsenic, for example. However, for other metals, like cadmium, the freshwater WQC is substantially different (0.27 μg/L at 100 mg/L hardness) from the marine criterion of 8.8 μg/L. Therefore, for river segments or water bodies that have no saltwater influence, the potential for environmental impacts of certain metals may vary.

Data are presented in box and whisker plots, which consist of a five number summary including: a minimum value; value at the first quartile; the median value; the value at the third quartile; and the maximum value. The size of the box is a measure of the spread of the data with the minimum and maximum values indicated by the whiskers. The median value is the value of the data that splits the data in half and is indicated by the horizontal blue line in the center of the boxes. Graphs are presented for the entire LSJR (including tributaries) as well as the freshwater and saltwater portions of LSJR mainstem. Data used from the Florida DEP STORET database are of higher quality but are less abundant than data from the EPA STORET. Only total metal concentrations were used in this report, rather than the preferred dissolved metal concentrations, which are used in calculation of water quality criterion values. Total values were used because the dissolved metal concentrations were not reported to a large extent and in many cases dissolved values only accounted for less that 5% of the total data reported. Additionally, negative values were removed and values designated as present below the quantitation limit (QL) were replaced with the average of the method detection limit (MDL) and practical quantitation limit (PQL). For "non-detect" values and values designated as "zero" half of the MDL was used.

5.2.2. Sediment

5.2.2.1. Sediment Data Sources

The data used in this report came from several major studies carried out on the Lower St. Johns River from 1983 to 2007. They were conducted by the SJRWMD (**Delfino, et al. 1992**: **Delfino, et al. 1991a**; **Durell, et al. 2004**; **Higman, et al. 2013**) and the Florida Department of Environmental Protection (**Delfino, et al. 1991a**; **Pierce, et al. 1988**), Data were used from the National Oceanographic and Atmospheric Administration's National Status and Trends Mussel Watch program (**NOAA 2007b**) and Benthic Surveillance Watch (**NOAA 2007a**) program. Data from STORET databases managed by EPA (modern) and DEP were included in this year's river report. The STORET data were from studies by the National Park Service Water Resources Division, Florida Department of Environmental Protection, and the Marine Research Institute of the Florida Fish & Wildlife Conservation Commission. Savannah Laboratories (**SLES 1988**), **Cooksey and Hyland 2007**, and **Dames and Moore 1983** also generated data that were analyzed in this report. The best and most recent data came from an extensive set of studies conducted by the SJRWMD. This study began in 1996 and provides a long-term sediment quality assessment of the LSJR (**Durell, et al. 2004**; **Durell, et al. 1997**; **Higman, et al. 2013**).

A summary of the sources of data is given in Appendix 5.2.A. The database that was generated represents a substantial portion of existing data for LSJR contaminants. It is not exhaustive however, and should be considered a starting point from which omitted past and future studies can be added. In particular, modern pesticides, other important priority pollutants and emerging pollutants, such as endocrine disruptors, should also be included. Future additions of data on concentrations of contaminants in water and organisms will also add to the quality of the assessment.

The contaminants we selected for evaluation had the highest abundance of data available for several years and adequate site information. Sometimes we omitted potentially important contaminants because of analytical differences between studies. The data were first compiled from each source for approximately 200 analytes at nearly 500 sites, over a span of 20 years, and then were culled for location and analytical comparability. We omitted data from some years when the numbers of samples were too few, or when extreme values distorted the analysis. For example, Deer Creek samples in 1991 that consisted of nearly pure creosote (**Delfino, et al. 1991b**) were omitted.

Sediment contamination was assessed by calculating average concentrations, percent exceedances of sediment quality guidelines, and average toxicity quotients, or toxicity pressure. These parameters were compared between years and regions of the river. Data below the detection limit were evaluated as zeroes in these calculations. The numbers of samples for each contaminant, year, and area are given in Appendix 5.2.B.

Trends were assessed by plotting median annual concentrations against time and determining the significance of an upward or downward slope of any line (Spearman Rank correlation coefficients $p<0.05$). Because of the limitations of the data, all trends were confirmed by graphical analysis and Pearson Product coefficient > 0.5. Trend statistics are given in Appendix 5.2.C.

Advances in analytical technology during the last 20 years have dramatically reduced the concentration at which some chemicals can be detected. This can skew interpretations of temporal trends, which we attempted to avoid by transforming the zero values in the data to minimum detectable levels. Where possible, the reported minimum detection limits were substituted for zero values. In some cases, we estimated a minimum level of detection by finding the lowest nonzero value in a given year and halving it. Using minimum detection limits reduces the possibility of erroneously concluding there is an increasing trend because of differences in analytical detection limits.

There are numerous sources of variability in reported sediment concentrations, including analytical differences, sampling variations, physical and chemical characteristics of the sediment, and even differences in definitions of reporting parameters such as minimum detectable limits. Furthermore, there are large differences in the numbers of samples in different regions, all taken at irregular intervals. These data gaps limit the applicability of many different standard statistical tests. Thus, major harmful contaminants and their spatial and temporal trends can be difficult to positively identify and requires judicious use of statistics and careful review of all data. Box and whisker plots of the data are given in Appendix 5.2.D, which illustrate the distribution of the values for each contaminant in each region for each year.

5.2.2.2. Sediment Quality Guidelines

Environmental toxicology is the study of the effects of contaminants on ecosystem inhabitants, from individual species to whole communities. While toxicity is often viewed in terms of human health risk, human risk is one of the most difficult toxicity "endpoints," or measures, to accurately quantify. It is environmental toxicity, or effects on ecosystems and aquatic organisms, that is the focus of our assessment of contaminants in the LSJR although human health effects from mercury in fish are discussed.

The environmental impact of a toxic compound can be evaluated several ways. One way is by comparing the concentrations in the LSJR to various toxicity measures. When the concentration of a contaminant in sediment is greater than the toxicity measure, it is an ***exceedance***. Most sediment quality guidelines for contaminants are based on the impact of contaminants on sediment-dwelling benthic macroinvertebrates, assessing both the individual species' health and the community structure. Since these organisms are at the beginning of the fisheries food chain, their health is a good indicator of general river health. One toxicity measure that is quite protective of the health of aquatic organisms is a ***Threshold Effects Level*** (**TEL**). This is the concentration at which a contaminant begins to affect some sensitive species. When the number of sites that have concentrations greater than the TEL is high, there is a higher possibility that some sensitive organisms are affected. A second, less protective guideline is the ***Probable Effects Level*** (**PEL**). This is the concentration above which many aquatic species are likely to be affected. The TEL and PEL sediment quality guidelines for marine systems are used in this assessment, with emphasis on the latter. These were the guidelines that were most widely available for the compounds of interest, plus much of the heavily impacted areas are in the marine section of the LSJR. Some alternative guidelines are used and identified for some compounds for which there were no marine TEL or PEL guidelines (**MacDonald 1994**; **NOAA 2008**). Specific values are listed in Appendix 5.1.A.

In an approach similar to **Long, et al. 1995** and **Hyland, et al. 1999**, we evaluated overall toxicity of nearly 40 chemicals on the river ecosystem by calculating a PEL quotient, or **toxicity pressure**, for each sample. The quotient is the concentration of a contaminant in the sediment divided by the PEL value. If the quotient, or toxicity pressure, is greater than one, adverse impacts on benthic organisms are probable. As the quotient increases, we can assume that the probability of toxic effects increases. The quotients are used to compare the effects of different chemicals and to understand their relative importance in the impairment of the river health.

While sediment quality guidelines are useful tools, it is important to appreciate the limitations of simple comparisons in the extremely complex LSJR. A major difficulty in assessing toxic impacts is that the accessibility, or bioavailability, of a contaminant to organisms may vary with sediment type. Two sediments with similar contaminant concentrations but different physical and chemical features can produce very different environmental impacts, and we know that LSJR sediments are highly variable. Furthermore, each sediment quality guideline can be specific to certain organisms and endpoints (e.g., death of fish, reproductive effects of sea urchin, sea worm community structure, etc.) and cannot easily be extrapolated to other organisms or endpoints. As a consequence, guidelines from different organizations are sometimes different. Finally, separate guidelines are often established for marine and freshwater environments, though few estuarine guidelines exist that apply to the LSJR. These challenges limit our assessment of the impacts of various contaminants on the LSJR to one that is general and relative in scope.

5.2.2.3. Regions of the LSJR

Within the LSJR basin, there is a large variation in the types of ecosystems, land uses, and hydrology. As a consequence, the distribution and potential impacts of contaminants will vary widely within the basin at any given time. To analyze sediment contaminants in the LSJR, we divided it into four regions (Figure 5.2) with roughly similar hydrologic and land use characteristics. Where possible, trends were tracked within each region, and comparisons were made between the regions.

One region, Area 1, is a composite of the basins of three tributaries on the western side of the LSJR. The western tributaries area is composed of the Trout River (including Moncrief Creek and Ribault River tributaries), Long Branch Creek, the Cedar-Ortega system, Big Fishweir Creek, and Rice Creek. Despite their distance from one another, they were combined because they share the unfortunate characteristic of having such high levels of contamination for some chemicals that they mathematically obscure trends in the rest of the lower basin. The northernmost region, Area 2, the north arm, stretches from the coast at Mayport to Talleyrand, and has an extensive maritime industry. It is strongly tidal with a range of salinity from marine to estuarine. Moving south, the next region is Area 3, or the north main stem, which includes urban Jacksonville and extends down to Julington Creek. The southernmost region in the LSJR, Area 4 or the south main stem, stretches from the Duval County boundary, past Palatka to the Ocklawaha and fresher water. Additional information about the different regions is given in Appendix 5.2.E.

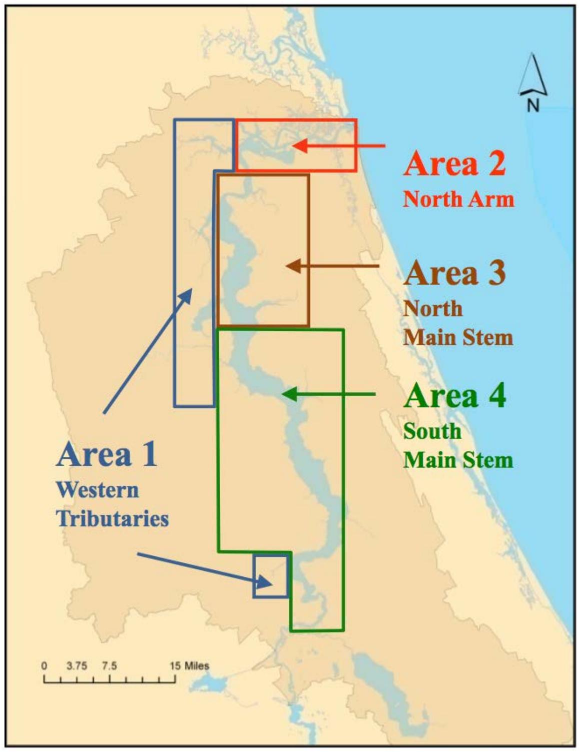


Figure 5.2 Areas of the LSJR studied for sediment contamination: Area 1 – western tributaries (including Trout River, Moncrief Creek, Ribault River, Long Branch Creek, Cedar-Ortega Basin, and Rice Creek); Area 2 – north arm; Area 3 – north main stem; Area 4 – south main stem. See Appendix 5.2.E for additional details.

5.3. Toxics Release Inventory: Point sources of contaminants in the LSJR region

The EPA's Toxics Release Inventory (TRI) program was established as a provision of the Emergency Planning and Community-Right-to-Know Act designed to protect communities from chemical hazards. The legislation was enacted in 1986 after serious industrial accidents in Bhopal India and in West Virginia resulted in numerous fatalities. The program was expanded under the 1990 Pollution Prevention Act so that today the TRI program requires facilities to report the quantities of more than 650 toxic chemicals that they release into the environment. Annually, they must report how much of each of these compounds is released on-site into the air, to surface water, to groundwater, to landfills, and to surface impoundments. They must also quantify how much they treat on-site and how much is transported off-site for treatment or disposal (e.g., to publicly-owned municipal treatment plants or to landfills). Facilities are not required to report their releases if they have fewer than 10 employees or if they discharge less than various threshold limits for different chemicals (**EPA 2015c**). The reported quantities may be derived from direct measurement, modeling estimates, or by "emission factors." The emission factors are usually averages of available data on emission rates of facilities in a particular source category (e.g., electric utilities, on-road vehicles) (**EPA 2013a**).

The TRI provides information that can be used to estimate point source loading of hundreds of chemicals released into the environment by dozens of industries. Local, statewide or national trends can be examined. We determined the annual loading of toxic compounds into the LSJR basin from 2001 to 2013 using data from EPA's TRI-NET database (**EPA 2015a**). Emissions into the atmosphere and discharges into LSJR surface waters were analyzed since chemicals released to these media are most likely to affect the LSJR, though significant discharges to land are also reported for many industries (Table 5.1). The environmental impact of atmospheric emissions is more difficult to determine than direct surface water discharges because of uncertainties in the fate of chemicals in the atmosphere and the potential impact from both long-range and local sources. However, higher local emissions will certainly increase the likelihood of local impact. In the following discussion, atmospheric emissions are addressed separately from surface water discharges.

Analyses of air emissions included all reporting facilities in the nine counties in the LSJR watershed: Clay, Duval, Flagler, Putnam, St. Johns, Volusia, Alachua, Baker, and Bradford. Even if facilities are not located directly on the river, nearby emissions are potential sources of pollutants in the river, though exactly how much finds its way into the river is largely unknown. For discharges into the LSJR surface waters, we included facilities that discharged directly into the SJR or its tributaries, as determined by the Form R report submitted by the facilities to the EPA. It is important to note that the magnitude of discharges or emissions does not always directly relate to human health effects or environmental harm. The Risk-Screening Environmental Indicators (RSEI) is a companion EPA program that uses TRI data to screen for overall toxicity (**EPA 2013c**). Quantities of chemicals, their individual toxicity, their fate in the environment, and their proximity to people are used to determine discharges of toxicity, rather than pounds. The relative importance of major emissions and discharges to chronic human health is addressed using the results of the RSEI model, although data are only available until 2011. It is important to note that the RSEI analysis does not indicate that there is a human health risk. It only indicates which emissions and discharges in our local environment are the most likely to have chronic human health risks associated with them.

Table 5.1 Reported Releases of Chemicals by Industries in the LSJR Basin (EPA 2015c)

Releases of Chemicals to the Atmosphere[1]				
Year	Total Tons	No. Chemicals[2]	No. Industries	No. Facilities
2001	7,928	69	21	79
2002	8,016	69	21	80
2003	7,697	67	21	78
2004	7,736	68	21	75
2005	7,258	62	21	73
2006	6,898	61	21	71
2007	6,236	6	20	71
2008	5,883	60	21	76
2009	3,774	53	21	70
2010	3,965	55	21	71
2011	3,055	56	21	74
2012	2,179	54	21	71
2013	2,176	59	21	78
Releases of Chemicals to the LSJR and Tributaries[3]				
Year	**Total Tons**	**No. Chemicals[2]**	**No. Industries**	**No. Facilities**
2001	152	28	10	15
2002	168	34	11	16
2003	233	30	10	14
2004	261	22	7	10
2005	302	23	8	11
2006	136	24	6	10
2007	216	28	7	11
2008	188	30	9	12
2009	278	27	8	11
2010	162	29	8	11
2011	205	30	7	11
2012	269	29	7	10
2013	203	26	6	9

1 Chemical releases from facilities emitting into the atmosphere in nine counties of the LSJR watershed
2 Number of unique chemicals or chemical classes released.
3 Chemical releases from facilities discharging to the surface waters of the LSJR and its tributaries.

Typically, industrial facilities emit more chemicals into the atmosphere than into surface water (Table 5.1). The reporting facilities in the nine LSJR counties released 91% of their waste into the atmosphere. These numbers do not include the on-site releases to landfills and surface impoundments.

Between 2001 and 2013, the reported annual release of chemicals to the atmosphere declined by over 70% to 4.4 million pounds (Figures 5.3 and 5.4). Reductions in emissions of hydrochloric and sulfuric acids by St. Johns River Power Park and Northside Generating Station, Seminole Electric and Gainesville Regional Utilities at Deerhaven were responsible for most of the decline. Sulfuric acid declined the most with a 6.2 million pound or 79% reduction over 13 years. Emissions declined for 58 of the 83 reported chemicals between 2001 and 2013. Ammonia, hexane and phenol were major exceptions with increases of 63%, 159% and 595%, respectively.

Despite the substantial reductions in acid gas emissions (sulfuric, hydrochloric and hydrofluoric acids), they still comprised 63% percent of the chemicals reported to be released to the LSJR region atmosphere in 2013, mostly released by electric utilities. Of the total atmospheric releases in 2013, 30% were composed of methanol, ammonia and styrene that were emitted primarily by electric utilities and the transportation equipment and paper industries,. The remaining chemicals released into the atmosphere were organic and inorganic compounds such as polyaromatic hydrocarbons and metals discussed in more detail in Sections 5.4 and 5.5.

In 2011 (the most recent year for which the RSEI model has data), regular emissions of sulfuric acid had the highest potential for chronic human health risk of all reported atmospheric releases, followed by cobalt, arsenic, and chromium, which were all emitted by the electric utilities. An accidental release of ethylene oxide by BAE Shipyards was also significant in 2011. Releases of formaldehyde by Georgia-Pacific and benzene by BP Products were also among the top ten atmospheric releases that had the highest potential for human health risks (**EPA 2013c**).

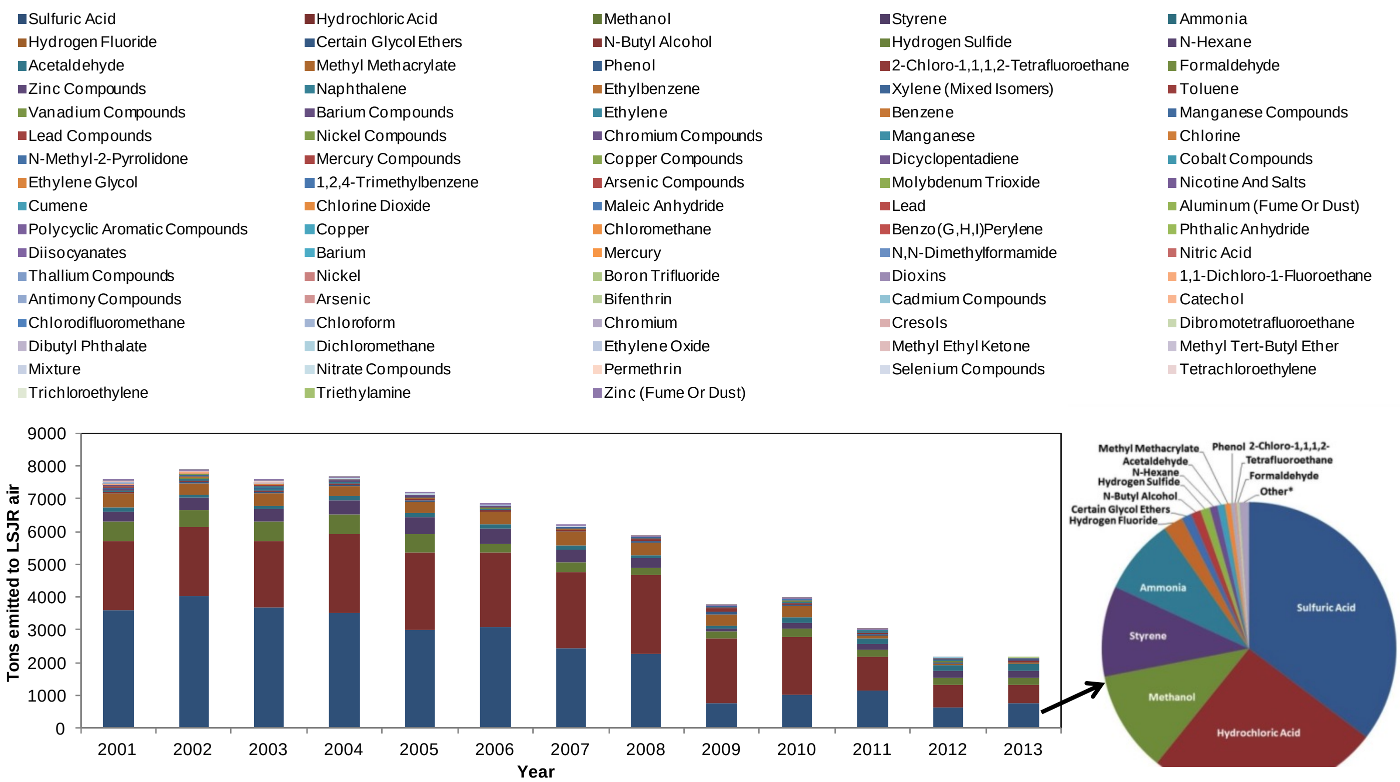


*Figure 5.3 Trends and status of 83 chemicals released to the atmosphere by industries in the nine-county LSJR basin as reported in the Toxics Release Inventory (**EPA 2015c**). Inset shows the distribution of 2,176 tons of chemicals emitted in 2013. The Other category in the inset is composed of 44 chemicals ranging from 3.3 tons of zinc to 40 milligrams of dioxins.*

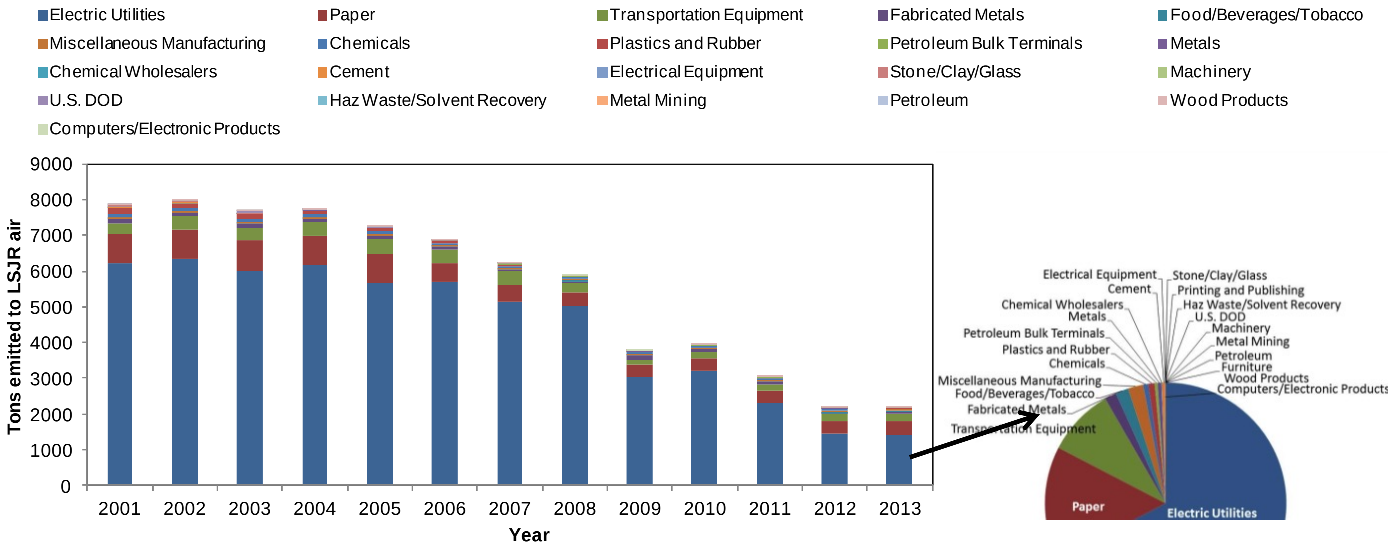


*Figure 5.4 Trends and status of 23 industries releasing chemicals to the atmosphere in the nine-county LSJR basin as reported in the Toxics Release Inventory (**EPA 2015c**). Inset shows the major industries emitting 2,176 tons of chemicals in 2013.*

Unlike atmospheric emissions, surface water discharges into the LSJR did not decline between 2001 and 2013, but have increased by 34%. Fluctuations in the extremely large discharges of nitrate and manganese by the paper industry and U.S. DOD affected overall SJR loading during the decade (Figures 5.5 and 5.6). Of the chemicals reported to be released into surface water in 2013, 12 were discharged at greater rates since 2001 and 12 chemicals were discharged at lower rates. The electric utility industry experienced an increase of 186% (nearly 15,000 pounds) in total annual chemicals discharged between 2001 and 2013, much of it in the form of nickel, barium, and cobalt compounds.

In 2013 most of the chemicals reported to be discharged directly into the SJR and its tributaries were nitrates released by the U.S. Department of Defense (over 318,000 lbs.) and manganese by the pulp and paper industry (51,000 lbs.). The paper industry reported no nitrate discharges in 2013, in contrast to 2013 when 105,000 pounds were reported. The nitrate and manganese discharges represented 91% of the total quantity of chemicals released into the LSJR in 2013 (Figures 5.5 and 5.6).

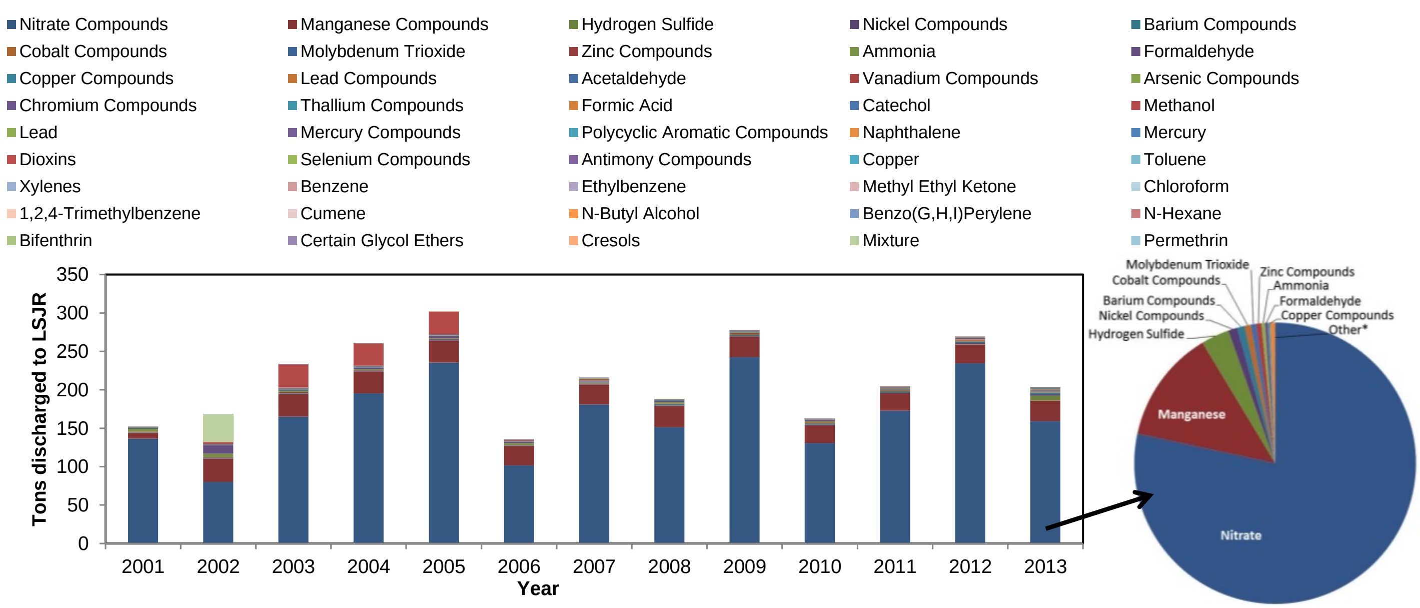


*Figure 5.5 Trends and status of 46 chemicals released to the LSJR and its tributaries as reported in the Toxics Release Inventory (**EPA 2015c**). Inset shows the distribution of over 400,000 pounds of chemicals discharged in 2013. The Other category in the inset is composed of 15 chemicals ranging from 510 pounds of lead compounds to a few milligrams of dioxins.*

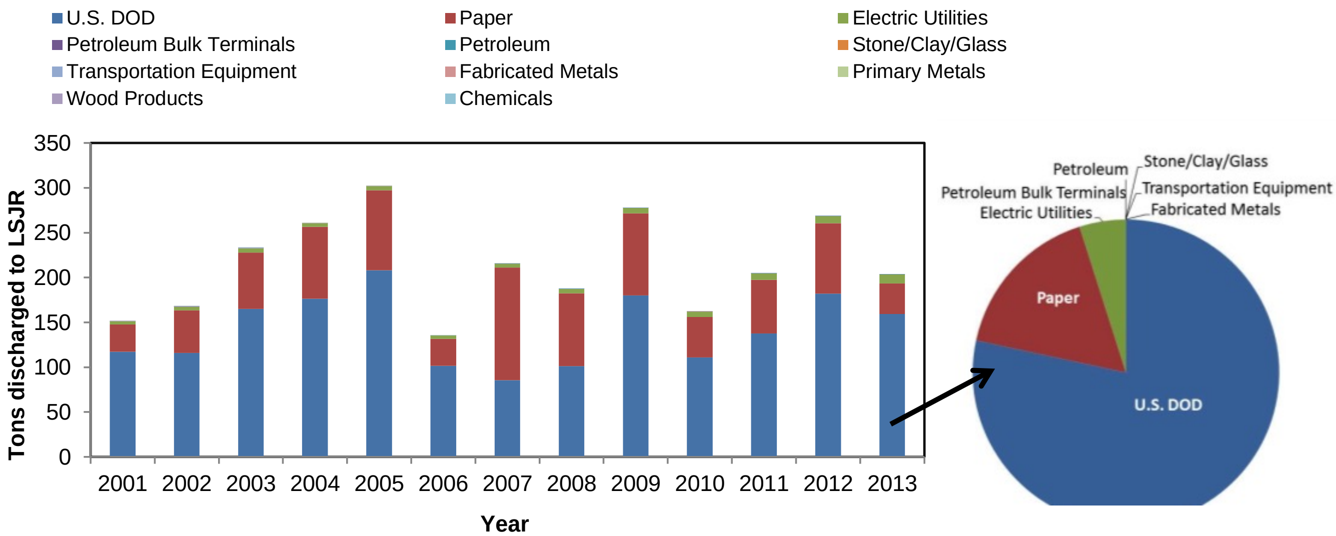


*Figure 5.6 Trends and status of 11 industries releasing chemicals into the LSJR and its tributaries as reported in the Toxics Release Inventory (**EPA 2015c**). Inset shows the major industries discharging over 400,000 pounds of chemicals in 2013.*

An analysis of toxicity loading into the LSJR surface waters by industries is greatly hindered by the fact the St. Johns River Power Park/Northside Generating Station, a major discharger, is not included in the EPA RSEI model because there is insufficient or questionable information about the segment of the river where it discharges its effluents. This may result from the reverse flow of the river causing difficulties with the model accuracy or due to inadequate flow information about the region from the National Hydrography Dataset used in the model (**EPA 2013b**). However, of the remaining discharges in 2013, arsenic, mercury, copper and polyaromatic hydrocarbons released by the other electric utilities contributed most of the total toxicity along with lead, mercury and dioxins discharged by the pulp and paper industries. The major pathway to exposure was found to be fish ingestion.

In summary, industries in the LSJR region reported the release of 4.8 million pounds of chemicals into the air and into the river and its tributaries in 2013, with 91% released into the air. Local emissions to the atmosphere, mostly from electric utilities, are primarily composed of acid gases followed by methanol, styrene, and ammonia. Air emissions have declined by more than two-thirds between 2001 and 2013, which is similar to the rest of the state (**EPA 2015b**). The LSJR surface waters received over 400,000 pounds of chemicals in 2013, mostly nitrates and manganese released by the U.S. Department of Defense and the paper industry. The rate of discharge of chemicals into the LSJR surface waters in 2013 is 34% greater than in 2001 while the rest of the state discharged 24% less since 2001.

Of all atmospheric emissions in the LSJR region in 2011, sulfuric acid and metals emitted into the atmosphere by electric utilities were most likely to cause chronic human health effects. Of surface water discharges in the LSJR in 2011, metals, polyaromatic hydrocarbons and dioxins discharged by electric utilities and the paper industry had the highest potential for human health risk. It is important to note that this does not mean that there is a human health risk. It means simply that of all the chemicals released into our local environment by industry, these are the most likely to be the most significant in terms of human health.

Overall, TRI data suggest that the mass of contaminants released to the atmosphere from point sources in the LSJR region has significantly declined over a decade though little change in overall surface water discharges has occurred. These reductions in atmospheric emissions may be related to the recently enacted rules for reducing air emissions of mercury and other toxic compounds from coal-fired utilities (**EPA 2013d**). Emissions are frequently estimated from production-dependent emission factors, thus the decline in reported emissions may reflect the general decline in U.S. industrial productivity during the last several years.

The **STATUS** of point sources of toxics emitted into the atmosphere is ***satisfactory*** because the rate of emissions is similar to the rest of the state and the **TREND** is ***improving***. The **STATUS** of point sources of toxics discharged into the LSJR surface waters is ***unsatisfactory*** because the rate of discharges exceeds the rest of the state, and the **TREND** is ***unchanged***.

5.4. Polyaromatic Hydrocarbons (PAHs)

5.4.1. Background and Sources: PAHs

Polyaromatic hydrocarbons are a class of over a 100 different chemicals, some of which are carcinogenic. They are often found in the environment in complex mixtures. Sometimes the patterns of distribution of the different types of PAHs can give clues to their sources and fates. They are often subdivided into classes of small, Low Molecular Weight (LMW) compounds, and larger High Molecular Weight (HMW) compounds. The two subclasses of PAHs tend to have different sources, environmental fates, and toxic effects, although there is considerable overlap in their characteristics.

PAHs arise from two major pathways. Pyrogenic ("fire"-generated) PAHs are formed during the combustion of organic matter, including fossil fuels. The PAHs formed by combustion tend to be the HMW type. Petrogenic ("petroleum"-generated) PAHs are also formed naturally and are precursors and components of complex organic matter including oil, coal, and tar. Petrogenic PAH mixtures tend to have more of the LMW type of PAH.

Although PAHs are naturally occurring, large quantities are introduced into the environment by human activities, particularly through fossil fuel handling and combustion. About 80% of PAH emissions are from stationary sources such as power plants, and 20% come from mobile sources such as automobiles and trucks, but the distribution can change with locale. Urban environments have more vehicular-related PAHs than rural or agricultural areas (**ATSDR 1995**). They may also be introduced into the aquatic environment from creosote in preserved wood, which may be a significant historic source of PAHs in the north main stem of the LSJR.

PAHs are mainly introduced into water bodies by the settling of PAH-laden atmospheric particles into the water, and by the discharge of wastewaters containing PAHs. Spills of petroleum products and the leaching of hazardous waste sites into water bodies are other ways that PAHs enter the aquatic environment.

5.4.2. Fate: PAHs

PAHs have a low affinity for the water phase and will tend to bind to phase boundaries, such as surface microlayers and the surface of particles, particularly organic phases (i.e. organisms and the organic fraction of sediments) (**Karickhoff 1981**). Once they are in the water, the PAHs tend to settle into the sediments fairly quickly, especially the HMW PAHs. The LMW PAHs also associate with particles, but to a lesser extent. As a result, the LMW PAHs can be transported farther by the river's tides and currents.

PAHs can be degraded by microbes and broken down by sunlight. Biodegradation accounts for the majority of removal in slow-moving, turbid waters typical of some of the LSJR. Many aquatic organisms can metabolize and excrete PAHs, particularly the LMW types, so the chemicals are not extensively passed up the food chain. However, HMW PAHs can accumulate in fish, amphipods, shrimp, and clams since they are only slowly degraded and reside in fats in organisms (**ATSDR 1995; Baird 1995**).

EPA has focused on 17 different PAHs primarily because they are the most harmful, have the highest risk for human exposure, are found in highest concentrations in nationally listed hazardous waste sites, and because there is information available about them (**ATSDR 1995**). In our analysis of the LSJR sediment data, 13 of the 17 EPA compounds were examined in detail as well as two that are not on the EPA list. These PAHs were selected for study because of the extensiveness of the data, the uniformity of the study methods, and their presence in the LSJR.

5.4.3. Toxicity: PAHs

Although PAH accumulation does occur in organisms from all trophic levels (**Cailleaud, et al. 2009; Carls, et al. 2006**), the PAH concentrations do not biomagnify up the food chain (**Broman, et al. 1990**). High molecular weight (HMW) PAHs are metabolized by most aquatic organisms to some extent; however, vertebrates have a greater metabolizing capacity than invertebrates (**Baussant, et al. 2001a; Cailleaud, et al. 2009**). Invertebrates, such as bivalves and polychaetes, are particularly slow to eliminate PAHs (**Baussant, et al. 2001a; Baussant, et al. 2001b**). PAH concentrations in several parts of the LSJR continue to be elevated (Section 5.3) as is reflected in the PAH concentrations observed in oysters collected in the LSJR (Section 5.3.4).

Because threshold PAH concentrations in the fish that result in toxicity (critical body residues) of PAHs are relatively constant, acute toxicity in fish is generally thought to be a function of the bioconcentration factor, resulting in narcosis. PAH toxicity occurs in lipids, particularly in the nervous system of fish, resulting in dysfunction (**Barron, et al. 2004; Barron, et al. 2002**). Specifically, the narcosis occurs due to PAH accumulation in the lipid bilayer of a biological cell membrane, which at elevated concentrations may disrupt the membrane integrity and function, leading to depression of the central nervous system (**Barron, et al. 2004; Barron, et al. 2002; Escher, et al. 2002; Escher and Hermens 2002; Van Wezel and Opperhuizen 1995).** Although narcosis is reversible, depending on the PAH concentration, it may result in erratic swimming, reduced predator avoidance, and prey capture ability. PAH acute toxicity values (concentrations causing mortality to 50% of the organism; LC50s) range from 5 to 2,140 mg/L, with the HMW PAHs (e.g. benzo(a)pyrene) being most toxic (**Neff and Burns 1996**).

The chronic toxicity of PAHs is poorly studied. **Donkin, et al. 1989** reported a reduced feeding rate and reduced growth in bivalves exposed to PAHs. Flounder fed a phenanthrene-contaminated diet exhibited decreased levels of 17B-estradiol (**Monteiro, et al. 2000**). While several studies have suggested deformities and long-term growth and survival effects in fish embryos exposed to low levels of PAHs, the mechanism of toxicity is still unclear (**Barron, et al. 2004; Incardona, et al. 2004**). **Sepúlveda, et al. 2002** reported the accumulation of both LMW and HMW PAHs in the livers of Florida largemouth bass collected from different locations in the LSJR. The liver PAH concentrations were highest in the largemouth bass collected from Palatka, followed by Green Cove and Julington Creek, with the lowest concentrations detected in those collected from Welaka. Largemouth bass with elevated PAH and pesticide residues in their livers had decreased sex hormones. Furthermore, females had both lower vitellogenin (egg yolk precursor molecule) concentrations and a lower ratio of fish gonad weight to body weight (gonadosomatic index; GSI), which could affect reproduction in the fish (**Sepúlveda, et al. 2002**).

5.4.4. Current Status: PAHs in Sediments

Polyaromatic hydrocarbons were found mostly at concentrations between the TEL and PEL guidelines. Most (~70%) of the samples in the western tributaries, Area 1, and the north arm, Area 2, had PAH concentrations exceeding the TEL, suggesting a low-level stress on sensitive benthic organisms by these compounds (Figure 5.7). The north arm had the most exceedances of the PELs, indicating that adverse impacts on benthic organisms from PAHs in that region are probable.

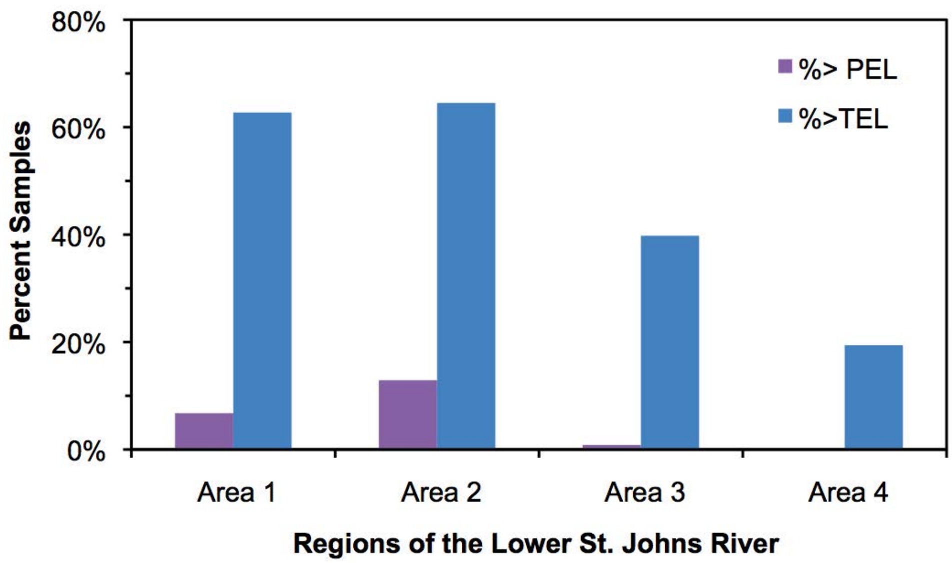


Figure 5.7 Percentage of samples from 2000-2007 with PAH concentrations that exceed Threshold Effects Levels (TEL) and Probable Effects Levels (PEL) for one or more PAHs. Area 1 – western tributaries; Area 2 – north arm; Area 3 – north main stem; Area 4 – south main stem. See text in Section 5.2 for data sources.

The toxicity pressure from PAHs was evaluated for each region using all data available since the 2000s. In Figure 5.8, the relative toxicity pressure from each PAH and the cumulative toxic pressure in each region can be compared. The PAHs exert similar overall toxic effects in Areas 1 and 2, but the PAHs responsible for the majority of the effects were different between the two regions, suggesting different sources of PAHs. The north arm, Area 2, is impacted most by acenaphthene (toxicity quotient >1) but fluoranthene, naphthalene, and 2-methyl naphthalene also contribute significantly to the toxicity pressure (toxicity quotient > 0.5).

In Area 1, the western tributaries, anthracene was the largest single contributor to PAH toxicity, while other PAHs exerted similar, low-level effects (Figures 5.8 and 5.9). Within Area 1, the highest levels for anthracene were found in Rice Creek in 2000-2003, with an average concentration nearly ten times the anthracene PEL (89 ppm), as shown in Figure 5.9. Levels near the PEL were also found in the Cedar-Ortega and Trout Rivers. Sediments in the north and south main stem regions (Areas 3 and 4) had average concentrations between the two guidelines, and were similar in their patterns of PAH contamination. The north arm, Area 2, where the shipping industry is prevalent, sediments had higher proportions of acenaphthene, naphthalene, and 2-methyl naphthalene, LMW PAHs, than the rest of the main stem.

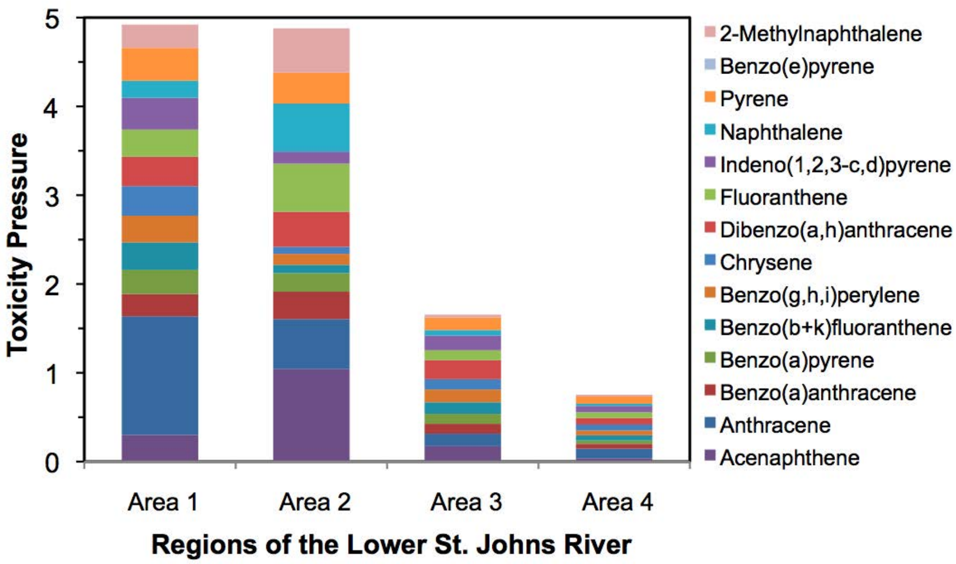


Figure 5.8 Average toxicity pressure of PAHs in sediments from 2000-2007 in the four areas of the LSJR. Area 1 – western tributaries; Area 2 – north arm; Area 3 – north main stem; Area 4 – south main stem. See text in Section 5.2 for data sources.

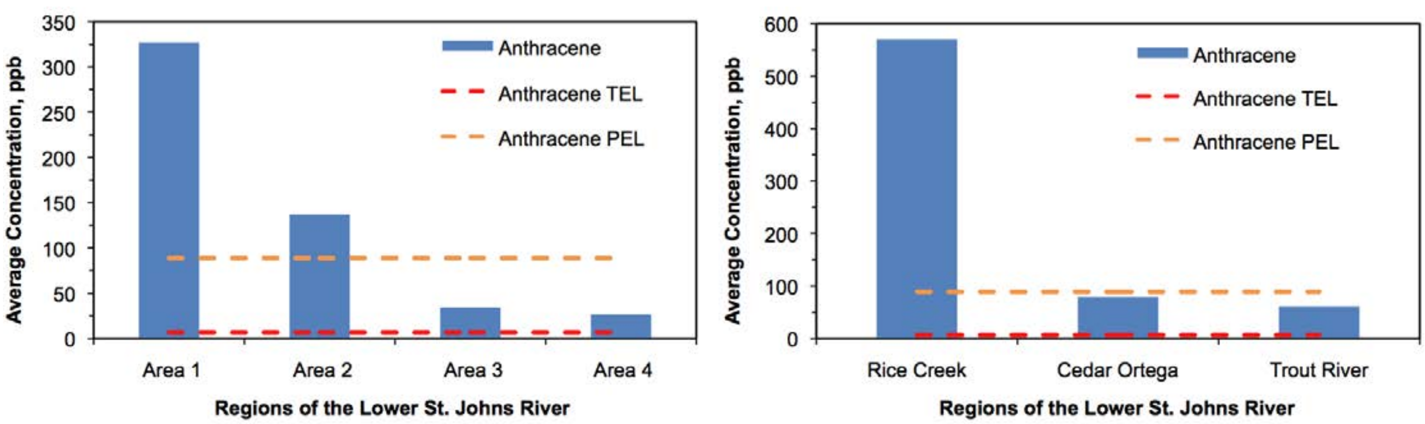


Figure 5.9 Average concentrations of anthracene in sediments from 2000-2007 in the four areas of the LSJR and in three streams in Area 1. Sediment quality guidelines for anthracene are shown as dashed lines. Area 1 – western tributaries; Area 2 – north arm; Area 3 – north main stem; Area 4 – south main stem. See text in Section 5.2 for data sources.

5.4.5. *Trends: PAHs in Sediments*

There was extreme contamination of Deer Creek from the Pepper Industries' creosote tanks near Talleyrand that was documented in 1991 (**Delfino, et al. 1991a**). Creosote is a product of coal tar that is used for wood preservation. While Deer Creek was the worst contaminated site, there were several other hot spots reported over the years for various PAHs. In the late 1980s, there were several sites all along the LSJR that had extremely elevated levels of PAHs, including acenaphthene in the north main stem, Area 3, at NAS Jacksonville (278 ppb), fluoranthene in Dunn Creek in the north arm, Area 2, (10,900 ppb), and pyrene in Goodby's Creek (8470 ppb). Most recently, the highest concentrations of naphthalene and anthracene (LMW PAHs) occurred in Rice Creek in 2002.

There are encouraging signs that some PAH levels have gone down since the late 1980s. Data were not collected continuously over the years, but for many PAHs, high concentrations found in the late 1980s declined dramatically to lower levels in 1996 where they have remained at lower concentrations. This pattern was particularly evident in Areas 3 and 4, the north and south main stem regions (Figure 5.10) and may reflect recovery from the creosote contamination during that time. Some of the PAH load in the western tributaries has also declined since the 1980s.

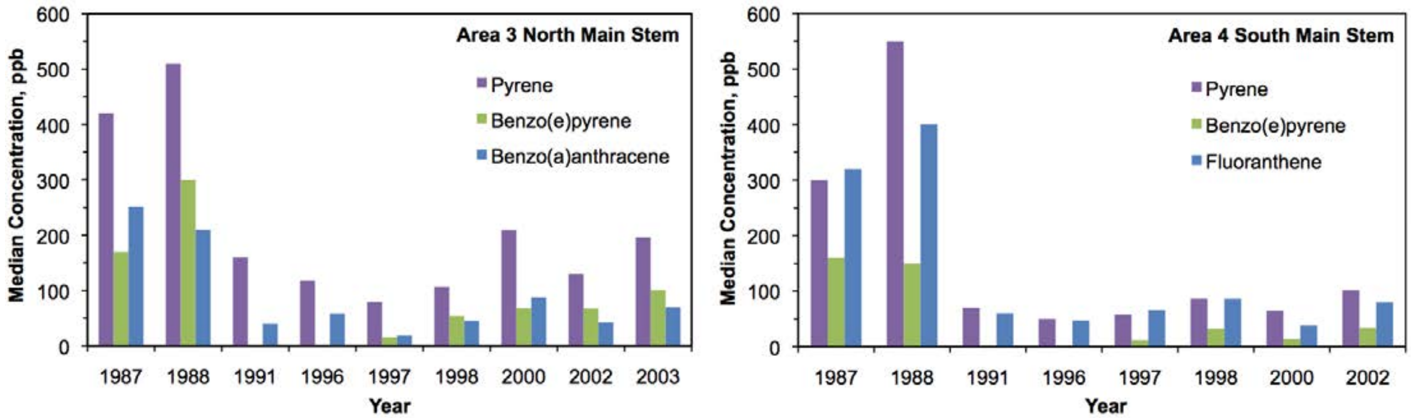


Figure 5.10 Median concentrations of PAHs in sediments from 2000-2007 in Area 3 (north main stem) and Area 4 (south main stem). Note that years are not continuous. See text in Section 5.2 for data sources.

However, since the 1990s, several PAH levels may be slowly rising in the main stem. While there are too few data points for a rigorous trend analysis, there may be a modest increase in most PAHs in Areas 3 and 4, similar to those shown for pyrene in Figure 5.11. Despite the uncertainty due to a lack of data, it is important to continue monitoring locales such as Clay and St. Johns Counties, which are rapidly becoming more urbanized, and can be expected to generate the PAHs typical of those land uses.

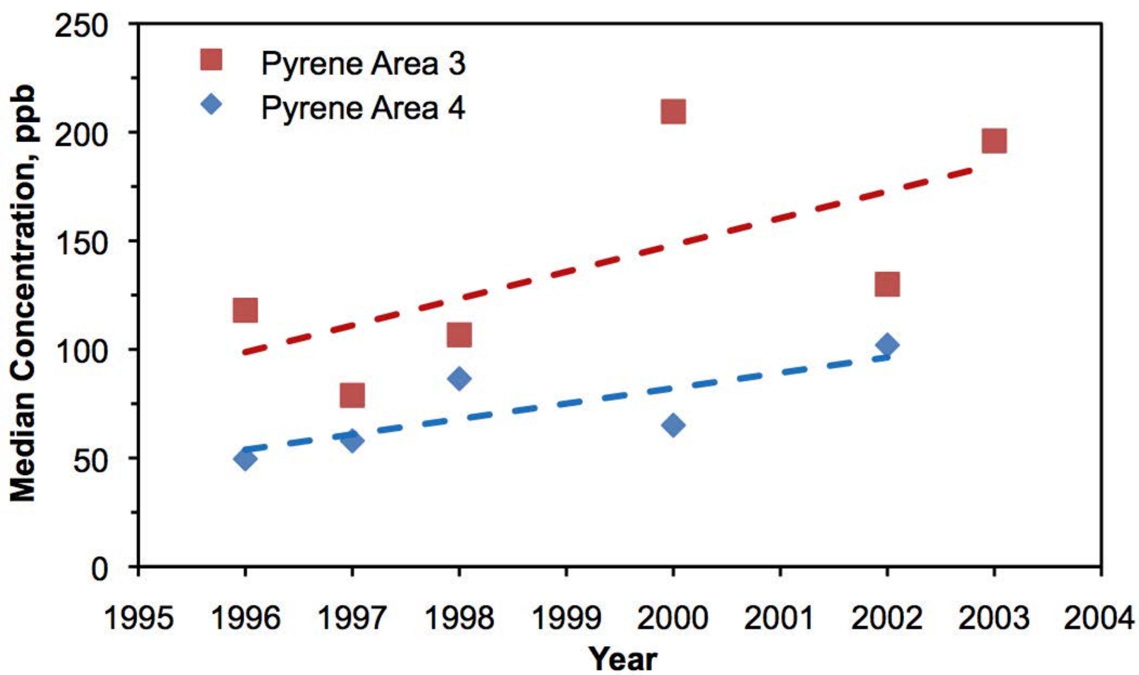


Figure 5.11 Apparent rise of median concentrations of pyrene in LSJR sediments since 1996 in Area 3 (north main stem) and Area 4 (south main stem). Dashed lines represent trend lines. See text in Section 5.2 for data sources.

5.4.6. *PAHs in Oysters*

In the Mussel Watch Project of NOAA's National Status and Trends Program (**NOAA 2007b**), oysters in Chicopit Bay in the north arm, Area 2, of the LSJR were analyzed for PAHs from 1989-2003 (Figure 5.12). These data show that there is a broad spectrum of PAH contaminants in Chicopit Bay oysters, but the PAHs with the most consistently high levels are pyrene and fluoranthene. There is no apparent decrease in the total PAH values in the oysters, despite decreasing trends of other contaminants such as PCBs, some pesticides, and some metals (**O'Connor and Lauenstein 2006**). In the 2000s, the sediment PAHs in the Area 2 north arm has a distribution similar to oysters with a predominance of fluoranthene, naphthalene and 2-methylnaphthalene. However, the high levels of acenaphthene found in the sediment in the 2000s were not reflected in oyster tissue.

The PAHs in the oysters have many possible sources, but several are often associated with petroleum contamination, a possible result of Chicopit's proximity to a shipping channel with high boat traffic. This appears especially true in 2003 when the concentrations in oysters approached the levels of the 1980s. The 2003 oysters also had more of the methylated LMW PAHs that suggest petrogenic origins of the compounds. Standards for consumption are sparse for PAHs (**EPA 2007**), but for the compounds for which there are standards (anthracene, acenaphthene, fluoranthene, fluorene, and pyrene), the levels found in these oysters would not be harmful. However, as noted, there are few direct data about the hazard of consumption of PAHs, including the notoriously carcinogenic benzo(a)pyrene or other PAH carcinogens.

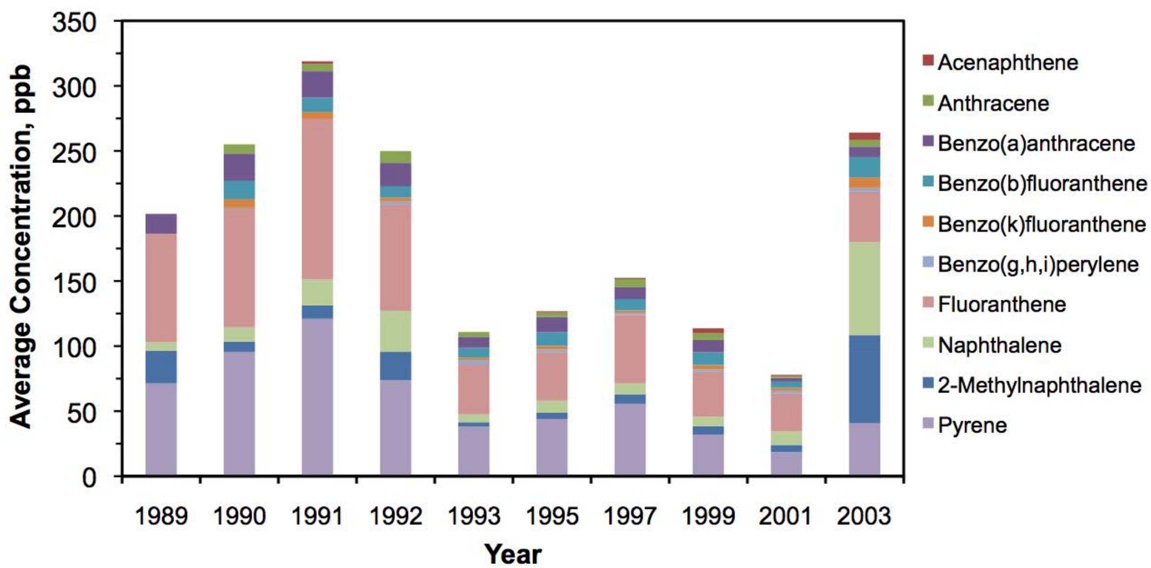


Figure 5.12 Concentration of select PAHs in oysters in Chicopit Bay, LSJR (Area 2 – north arm). Note that years are not continuous. See text in Section 5.2 for data sources.

5.4.7. *Point Sources of PAHs and related compounds in the LSJR Region*

Reported PAH emissions to the LSJR region atmosphere have dropped by 83% over the last decade, mainly due to reductions in emissions by electric utilities (**EPA 2015a**). In 2013 the total emitted PAHs was 112 pounds, 100 pounds of which came from the paper industry. Direct surface water discharges of PAHs have declined from nearly 20 pounds in 2001 to a pound in 2013, all of which is now released by electric utilities. Despite the decline in surface water discharges, PAHs represent one of the top ten chemicals that have the highest potential for human health risk of all discharges in the LSJR basin (**EPA 2013c**).

Overall, there was a significant drop in point source releases of PAHs and related compounds into the air and water in the LSJR region between 2001 and 2013. Several industries have shared in reducing the overall aromatic hydrocarbon loading to the region.

5.4.8. *Summary: PAHs*

Portions of the LSJR appear to still be recovering from severe creosote contamination from the 1980s, but there are likely to be additional petroleum and combustion sources. The PAHs occur at levels that may be problematic in some areas, and there continues to be widespread contamination. Near the port in the north main stem, the combined impacts from power plants, shipping, and the maritime industry are likely to cause this region to continue to be the most heavily impacted by PAHs into the future. There is direct evidence that these compounds reside in consumable organisms in the river in that area. There is a possible rise of PAHs in the southern main stem portion of the river, which may be beginning to suffer the same stress from urban impact that the north main stem experiences. In summary, PAHs in the LSJR are likely to be a significant source of stress to sediment-dwelling organisms, despite their overall decline since the 1980s. A drop in the release of PAHs into the region by industries since 2001 may effect a gradual improvement in the next few years if the emission rates remain stable or decrease. For these reasons, the **STATUS** of PAHs in sediments **is *unsatisfactory*** while the **TREND** in the north marine/estuarine section is ***improving*** and the **TREND** in the south fresh water section is ***worsening***.

5.5. Metals

5.5.1. Background

Metals are naturally occurring components of the mineral part of a sediment particle. Major metals in sediments are aluminum, iron, and manganese and these are often used to differentiate types of sediment (more like terrestrial soil or limestone bedrock). Sediment composition varies naturally with local geography and environment, and so the concentrations of metals in sediments and water bodies also vary naturally. Sediments in the main stem LSJR have widely different geologic sources. By contrast, the Cedar-Ortega system sediment characteristics suggest common geologic sources (**Durell, et al. 2004**; **Scarlatos 1993**). As a result of this natural variability, it can be difficult to determine if metal levels are elevated because of human activities or simply because of the nature of the sediments. Concentrations of metals of high concern, like lead or chromium, are often compared to aluminum concentrations to try to determine what amount is the result of human input (**Alexander, et al. 1993**; **Schropp and Windom 1988**). However, anthropogenic contributions of excess metals in aquatic environments are generally much greater than natural contributions (**Eisler 1993**).

Metals may enter aquatic systems via industrial effluent, agricultural and stormwater runoff, sewage treatment discharge, fossil fuel combustion, ore smelting and refining, mining processes, and due to leachate from metal-based antifouling paints (**Echols, et al. 2009; Evans, et al. 2000; Kennish 1997; Reichert and Jones 1994; Voulvoulis, et al. 2000**). Coal and oil combustion represent a substantial release of atmospheric metals, often fated for future deposition into water bodies. Metals are only present in these fuels in small quantities; however, massive amounts of fuel are combusted. Metallic contamination also occurs with various metal-working enterprises where metal fabrications are produced and processed. Another avenue for metals to enter into aquatic environments is from leaching from hazardous waste sites (**Baird 1995**). Naturally occurring trace metals such as copper, zinc, and nickel are essential micronutrients required by all organisms; however, in excess, these metals, as well as non-essential metals, such as arsenic, cadmium, lead, silver, and mercury may cause adverse biological effects in aquatic organisms (**Bielmyer, et al. 2005a; Bielmyer, et al. 2006a; Bryan and Hummerstone 1971; Bury, et al. 2003; Dallinger and Rainbow 1993**).

Copper and zinc are two of the most widely used elements in the world and as such are common pollutants found in freshwater and marine ecosystems. Copper enters aquatic systems through runoff from rivers adjacent to heavy metal mining areas (**Bryan 1976**); through sewage treatment discharge, industrial effluent, anti-fouling paints, refineries, as well as overflow from stormwater ponds (**Guzman and Jimenez 1992**; **Jones 1997**; **Mitchelmore, et al. 2003**). Copper is also a constituent of several pesticides commonly used to control algae. Zinc is a major component of brass, bronze, rubber, and paint and is introduced into water systems via commercialized businesses (smelting, electroplating, fertilizers, wood preservatives, mining, etc.) and rainwater run-off (**Eisler 1993**). Although there are freshwater environments with only a few micrograms of zinc per liter, some industrialized areas may have problematic concentrations of over 1000 μg/L Zn (**Alsop and Wood 2000**). Along with copper and zinc, nickel-containing materials make major contributions to many aspects of modern life. The uses of nickel include applications in buildings and infrastructure such as stainless steel production and electroplating; chemical production, such as production of fertilizers, pesticides and fungicides; energy supply, water treatment, and coin production (**Eisler 1988a; Hoang, et al. 2004; Nriagu 1980**). The largest use of nickel alloys and a major use of copper and zinc are in corrosion prevention. Although these applications have provided many benefits, they have resulted in increased environmental concentrations, which may have significant impact on aquatic life (**Hoang, et al. 2004; Pane, et al. 2003**). In the past, lead has also been used to a large extent in corrosion prevention, but legislation in the 1980s has limited the content of lead in paints, reduced the lead in gasoline, and eliminated the use of lead shot nationwide (**Eisler 1988b**). Current concerns about lead contamination in aquatic environments are mainly due to point-source discharges from mining, smelting, and refining processes, mostly for use in the production of batteries (**Eisler 1988b; WHO 1995**). Natural sources of lead such as erosion and atmospheric deposition from volcanoes and forest fires also contribute to the lead found in aquatic environments (**WHO 1995**). Elevated silver concentrations in aquatic animals occur near sewage outfalls, electroplating plants, mine waste sites, or areas where clouds have been seeded with silver iodide. The photographic industry has been the major source of anthropogenic silver discharges in the United States (**Eisler 1996**); however, over the last decade the use of silver, as silver nanoparticles, has substantially increased, particularly for applications in catalysis, optics, electronics, biotechnology and bioengineering, water treatment, and silver-based consumer products. Arsenic and many of its compounds are especially potent poisons, especially to insects, thereby making arsenic well suited for the preservation of wood, which has been its primary historical use. Chromated copper arsenate, also known as CCA or Tanalith, has been used worldwide in the treatment of wood; however, its use has been discontinued in several areas because studies have shown that arsenic can leach out of the wood into the soil, potentially causing harmful effects in animals and severe poisoning in humans (**Rahman, et al. 2004**).

5.5.1.1. Fate

Metals may be suspended in the water column for various time periods, depending on a variety of abiotic and biotic factors. In the water column, metals can reversibly bind to organic and particulate matter, form inorganic complexes, and be passed through the food chain (**Di Toro, et al. 2001**). Various chemical reactions favor the transfer of metals through the different phases. Ultimately, metals partition in the sediment over time, as has occurred in the LSJR; however, metals may be remobilized into the interstitial water by both physical and chemical disturbances.

Metal concentrations in saltwater generally range from 0.003-16 μg/L Zn (**Bruland 1980**; **Bruland 1983**), 0.13-9.5 μg/L Cu (**Kozelka and Bruland 1998**), 0.2 to 130 μg/L Ni (**DETR 1998**; **WHO 1991**), and from 0.001 to 0.1 μg/L Ag (**Campbell, et al. 2000**). The highest metal concentrations reported were measured in estuaries with significant anthropogenic inputs. However, in most cases the concentration of organic ligands, such as humic and fulvic substances, as well as the concentration of inorganic ligands exceed metal concentrations thereby forming complexes and rendering metals less bioavailable to aquatic organisms (**Campbell 1995**; **Kramer, et al. 2000**; **Stumm and Morgan 1996**; **Turner, et al. 1981**; **Wang and Guo 2000**). Aquatic animals, particularly zooplankton, have been shown to be highly sensitive to these metals (**Bielmyer, et al. 2006a; Jarvis, et al. 2013**). Lead concentrations in natural waters generally range from 0.02 to 36 μg/L, with the highest concentrations found in the sediment interstitial waters, due to the high affinity of this metal for sediment (**Eisler 1988b**).

Benthic biota may be affected by metals in the sediment, both by ingestion of metal-contaminated substrate and by exposure through the interstitial water. The presence of metals in the interstitial water is primarily controlled by the presence of iron sulfide in the sediments (**Boothman, et al. 2001**). All major pollutants will displace iron and tightly bind to sulfide, thus making them less available to cause toxicity to organisms.

5.5.1.2. Toxicity

Once in aquatic systems, most waterborne metals exert toxicity by binding to and inhibiting enzymes on the gill or gill-like structure of aquatic organisms (**Bielmyer, et al. 2006b; Bury, et al. 2003**). This leads to a disruption in ion and water balance in the organism and ultimately death, depending on the metal concentration and exposure time. In saltwater, fish drink water to maintain water balance and therefore, the intestine is another site for metal accumulation and ion disruption (**Bielmyer, et al. 2005b; Shyn, et al. 2012**). Ingestion of metal contaminated diets can also cause intestinal metal accumulation and potentially toxicity to the consumer (**Bielmyer, et al. 2005b; Bielmyer and Grosell 2011; Bielmyer, et al. 2012b**). Decreased respiration, decreased reproductive capacity, kidney failure, neurological effects, bone fragility, mutagenesis (genetic mutation), and other effects have been observed in aquatic biota after metal exposure. Several water quality parameters can modify the toxicity of metals including: salinity, DO, dissolved organic carbon concentration (humic and fulvic substances), sulfide concentration, pH, water hardness and alkalinity, as well as other variables (**Campbell 1995**). The toxicity of metals may therefore vary in different parts of the LSJR, reflecting the changes in water chemistry (**Ouyang, et al. 2006**) as well as the organisms that reside there. Metal toxicological studies using organisms or water from the LSJR are scarce. **Grosell, et al. 2007** and **Bielmyer, et al. 2013** collected *Fundulus heteroclitus* (killifish) from the LSJR and used them in acute (96 h) toxicological studies in the laboratory to determine the influence of salinity on copper, zinc, nickel, and cadmium toxicity to the larvae. As salinity increased, toxicity generally decreased for the metals tested. In freshwater, significant mortality to larval killifish occurred after exposure to copper (**Grosell, et al. 2007**), zinc (**Bielmyer, et al. 2012a**), nickel (**Bielmyer, et al. 2013**) and cadmium (Bielmyer, unpublished work) at concentrations reported in the LSJR over the past five years (see section 2.7); however significant larval mortality was only observed after exposure to higher nickel concentrations than those found in the LSJR (**Bielmyer, et al. 2013**). The presence of killifish is important in the LSJR because they are a common food source for many larger fish. Exposure to these metals for long time periods may cause deleterious effects, such as decreased growth and/or reproduction, in various species at even lower concentrations. Exposure to 50 µg/L for 21 days caused decreased growth in hybrid striped bass in freshwater; whereas, those exposed to the same concentration in saltwater did not suffer growth reduction (**Bielmyer, et al. 2006b**). Generally, larval fish are more sensitive to metals than adults, and invertebrates can be even more sensitive than larval fish (**Bielmyer, et al. 2007**). In water collected from Green Cove Springs, exposure to silver concentrations as low as 0.34 µg/L for the invertebrate crustacean, *Ceriodaphnia dubia* (common food sources for larval fish), and 6 µg/L for fathead minnows, respectively, caused 50% mortality to the organisms (**Bielmyer, et al. 2007**). These silver concentrations have been reported to occur in parts of the LSJR. Many zooplankton exposed to metals, particularly through their diets, have been shown to be very sensitive to metals (**Bielmyer, et al. 2006a**) and to accumulate metals (**Bielmyer, et al. 2012b**). Metal exposure to the lower trophic levels may impact higher-level consumers by decreasing food availability and/or by introducing metal exposure via the diet. **Sepúlveda, et al. 2002** reported the accumulation of both metal and organic contaminants in the livers of Florida largemouth bass collected from four different locations in the LSJR: Welaka, Palatka, Green Cove, and Julington Creek. The highest mean liver metal concentrations were found in bass from Julington Creek (silver, arsenic, chromium, copper, zinc) and Welaka (cadmium, mercury, lead, selenium, tin). The zinc concentrations accumulated in the liver of the fish from Julington Creek were similar to those observed in adult killifish after exposure to 75 µg/L Zn in the laboratory (**Shyn, et al. 2012**). Lead (Pb) can exist as an organometal and has a higher partition coefficient than the other metals discussed here; therefore, Pb would be preferentially distributed in more hydrophobic compartments (**Eisler 1988b**). Lead has been shown to exert toxic effects on a variety of aquatic organisms with sensitivity of some invertebrates as low as 4 µg/L (**Grosell, et al. 2006**). Chronic lead toxicity in fish includes neurological and hematological dysfunctions (**Davies, et al. 1976; Hodson, et al. 1978; Mager and Grosell 2011**).

5.5.2. Current Status and Trends of Metals in Water and Sediments

5.5.2.1. <u>Metals in Water</u>

The current overall STATUS in the mainstem of the LSRJ is *satisfactory* for all metals except Cu and Ag; and the overall STATUS in the tributaries is *unsatisfactory* for all metals. The TREND in the mainstem is *unchanged* and the TREND cannot be determined in the tributaries because of the lack of data.

The metals in the water column that we have evaluated in this study include arsenic, copper, cadmium, lead, nickel, silver, and zinc. Generally, in the last two to four years, a pattern of stabilized or reduced metal concentrations, particularly the maximum values, has been observed, as compared to previous years, in the LSJR mainstem with a few noted exceptions (discussed below). This reduction in metal concentration may reflect the recent efforts associated with TMDLs. Many tributaries, however, contain metal concentrations that exceed acceptable limits. Each metal is discussed in turn below.

With all but one exception (elevated maximum value) in 2000, the arsenic minimum, median, and maximum values in the LSJR mainstem have been below the WQC of 50 µg/L since 1997 (Figure 5.13). Doctor's lake and Moncrief Creek; however, have arsenic values that exceed acceptable limits (Figure 5.20A). In the LSJR, median cadmium values have been stable since 2010, and below WQC (Figure 5.14). The median cadmium values in Hogan Creek and the maximum values in Cedar River, McCoy Creek, and Moncrief Creek were elevated above WQC (with the assumed hardness value of 100 mg/L; Figure 5.20B). Copper was one of the more commonly found metals in the LSJR, based on this data set. For at least the past four years, maximum copper concentrations in the predominantly saltwater regions (Figure 5.15) of the LSJR and tributaries (Figure. 5.20C) have exceeded the WQC. Copper is by far most problematic in the tributaries where copper levels exceeded acceptable limits in the majority of the tributaries considered (Figure. 5.20C). Since 2010, maximum lead concentrations in the freshwater portion of the LSJR have been close to the freshwater criterion of 3.2 µg/L (Figure 5.16A); whereas, lead concentrations in the saltwater portions of the LSJR mainstem have been well below the saltwater criterion of 8.5 μg/L (Figure 5.16). In the tributaries, particularly Big Fishweir Creek, McCoy Creek, and Moncrief Creek, lead concentrations (median and maximum values) exceeded both freshwater and saltwater criteria (Figure 5.20D). Nickel concentrations in the entire LSJR have decreased from 2000 to 2010 and have remained stable since then, with concentrations well below the saltwater and freshwater criteria of 8.3 μg/L and 52 μg/L, respectively (Figure 5.17). Maximum nickel concentrations were above WQC in several tributaries (Fig. 5.20E). Median and maximum silver concentrations in the freshwater portion of the LSJR have been and continue to be elevated above the WQC of 0.07 μg/L (Figure 5.18). Alternatively, silver concentrations in the saltwater portion of the LSJR have been below the saltwater criterion of 2.3 μg/L in the saltwater portion of the LSJR mainstem and within acceptable limits since 2009 (Figure 5.18C). Several tributaries contain median and maximum silver concentrations which are above WQC (Figure 5.20F). Zinc concentrations have increased since 2012 in the saltwater portion and remained stable in the freshwater portion of the LSJR mainstem, but all zinc concentrations in the mainstem have still been below the WQC and within acceptable limits (Figure 5.19). Alternatively, in several tributaries, particularly Doctor's Lake, Dunns Creek, McCoy Creek, and Butcher Pen Creek, maximum zinc concentrations exceeded the WQC and were not within acceptable limits (Figure 5.20G).

The metals analyzed in this report are widely used and therefore continue to enter the LSJR through point and nonpoint sources. However, with a few noted exceptions (copper and silver) the majority of the metal concentrations in the water column of the LSJR mainstem were at or below WQC for the last three years. The metal concentrations in the tributaries; however, continue to be problematic. It should also be noted that sediments act as a reservoir and may still contain high metal concentrations (see below). If sediments are disturbed, metals may be remobilized into the water column and may negatively impact aquatic life in the LSJR. The magnitude of potential impact is dependent on many concurring abiotic and biotic factors.

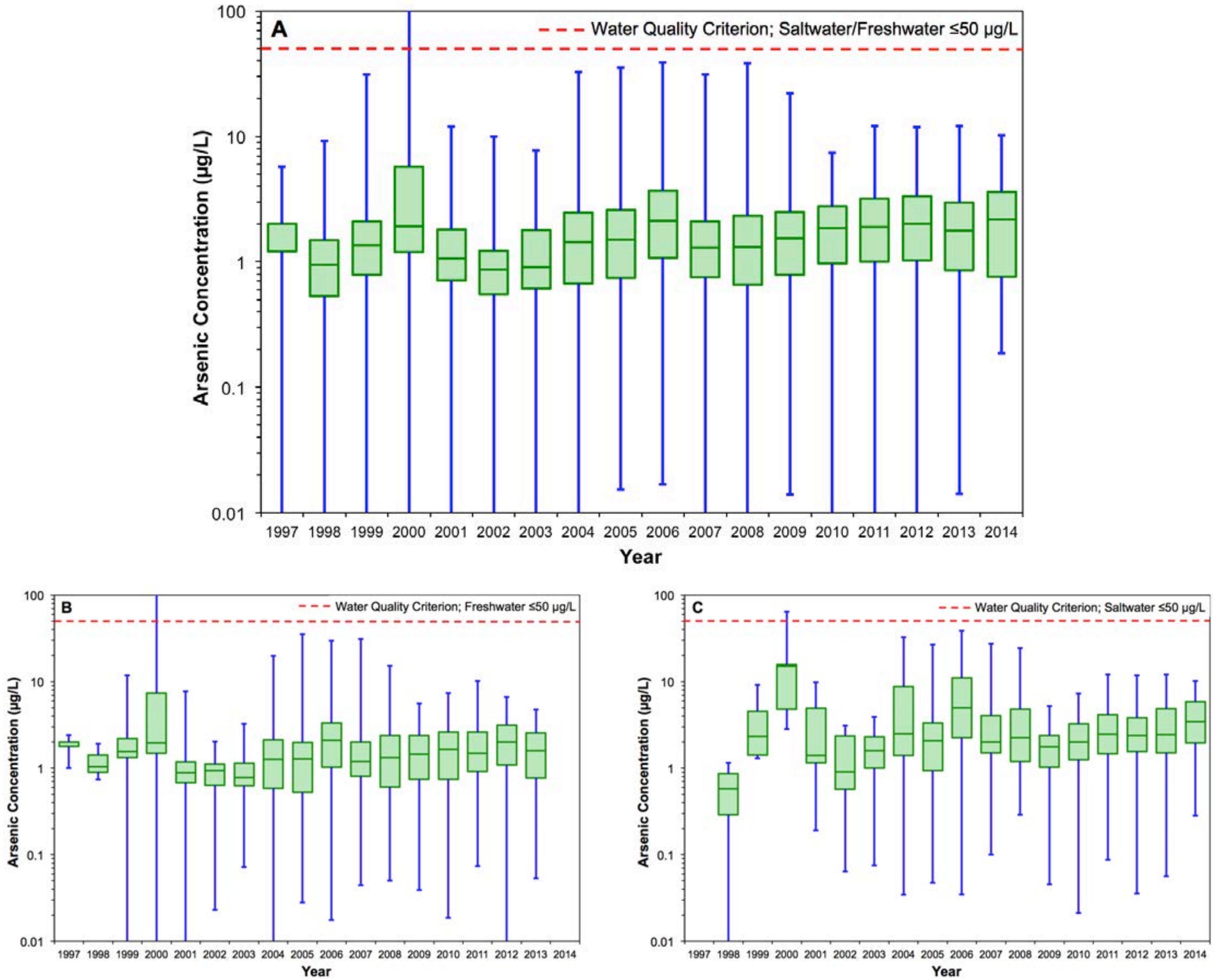


Figure 5.13 Yearly arsenic concentrations (µg/L) from 1997 to 2014 in A., the entire LSJR, B., the freshwater portion of the LSJR mainstem, and C, the predominantly saltwater portion of the LSJR mainstem. Data are presented as a box-and-whiskers plot with the green boxes indicating the median ±25% (middle 50% of the data) and horizontal lines indicate the median values. Blue whiskers indicate the minimum and maximum values in the data set. The dotted red horizontal line indicates the class III water quality criterion for both marine waters and freshwaters.

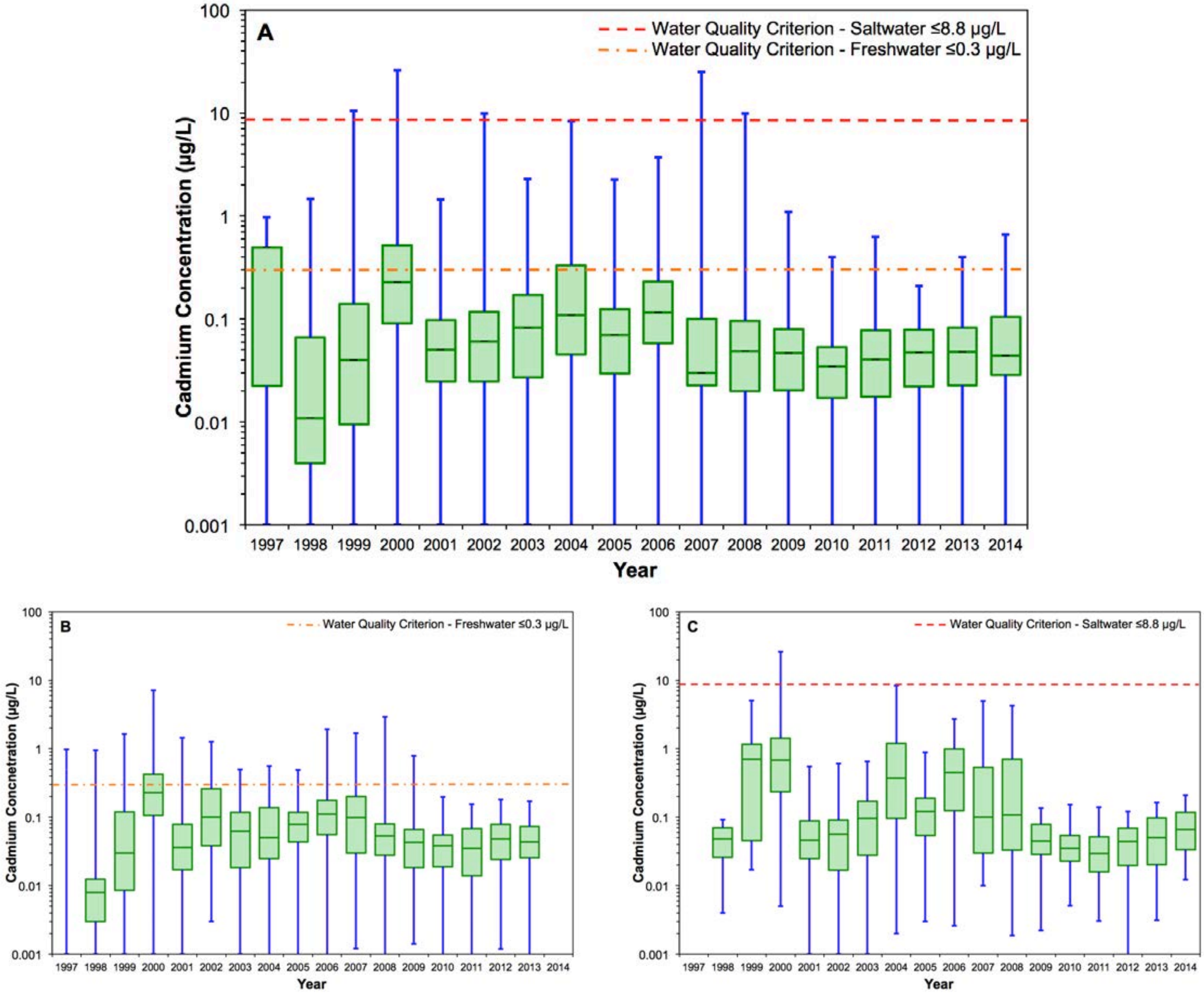


Figure 5.14 Yearly cadmium concentrations (µg/L) from 1997 to 2014 in A., the entire LSJR, B., the freshwater portion of the LSJR mainstem, and C, the predominantly saltwater portion of the LSJR mainstem. Data are presented as a box-and-whiskers plot with the green boxes indicating the median ±25% (middle 50% of the data) and horizontal lines indicate the median values. Blue whiskers indicate the minimum and maximum values in the data set. The dotted red horizontal line indicates the class III water quality criterion for predominantly marine waters and the dashed orange line indicates the criterion for mostly freshwaters.

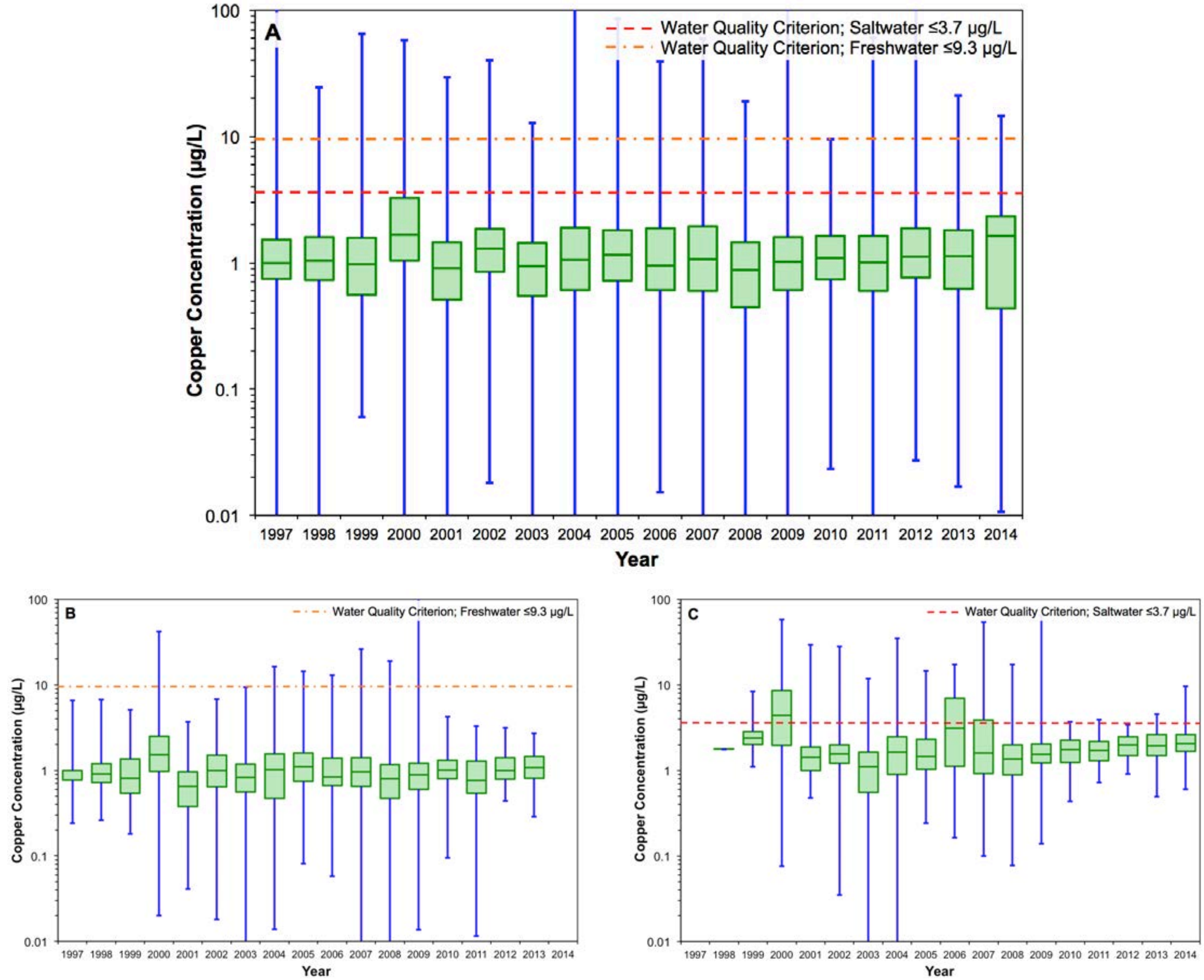


Figure 5.15 Yearly copper concentrations (µg/L) from 1997 to 2014 in A., the entire LSJR, B., the freshwater portion of the LSJR mainstem, and C, the predominantly saltwater portion of the LSJR mainstem. Data are presented as a box-and-whiskers plot with the green boxes indicating the median ±25% (middle 50% of the data) and horizontal lines indicate the median values. Blue whiskers indicate the minimum and maximum values in the data set. The dotted red horizontal line indicates the class III water quality criterion for predominantly marine waters and the dashed orange line indicates the criterion for mostly freshwaters.

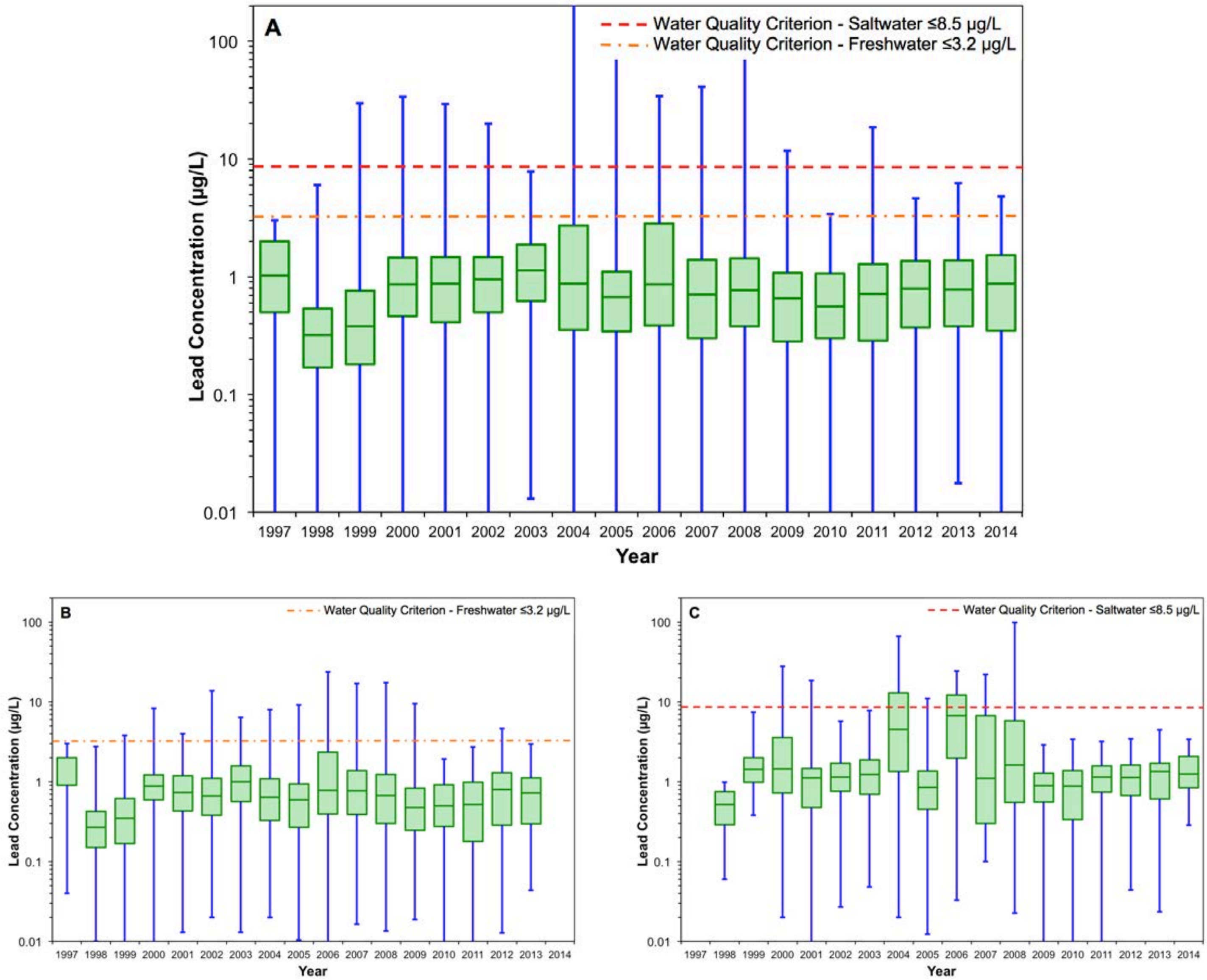


Figure 5.16 Yearly lead concentrations (µg/L) from 1997 to 2014 in A., the entire LSJR, B., the freshwater portion of the LSJR mainstem, and C, the predominantly saltwater portion of the LSJR mainstem. Data are presented as a box-and-whiskers plot with the green boxes indicating the median ±25% (middle 50% of the data) and horizontal lines indicate the median values. Blue whiskers indicate the minimum and maximum values in the data set. The dotted red horizontal line indicates the class III water quality criterion for predominantly marine waters and the dashed orange line indicates the criterion for mostly freshwaters.

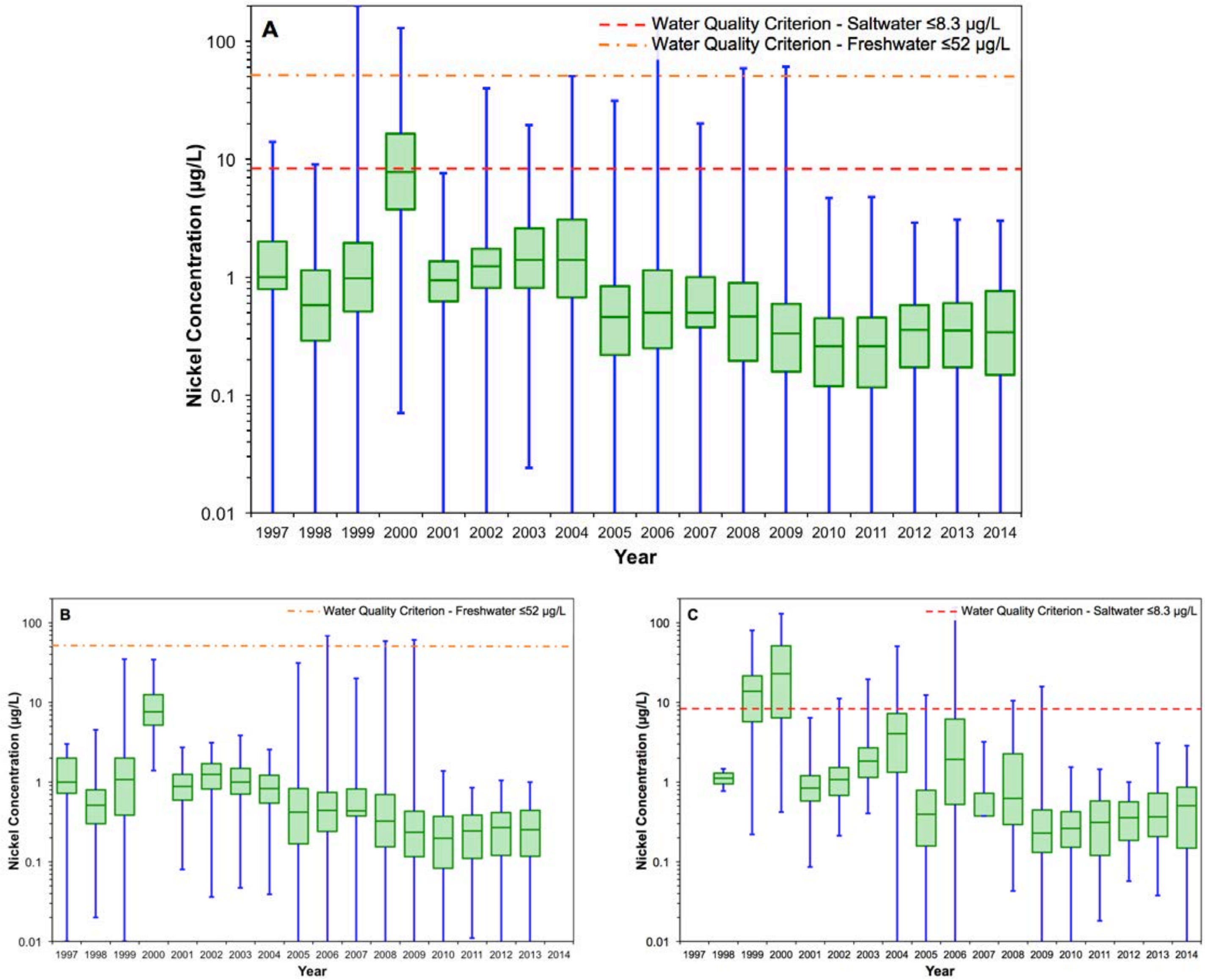


Figure 5.17 Yearly nickel concentrations (μg/L) from 1997 to 2014 in A., the entire LSJR, B., the freshwater portion of the LSJR mainstem, and C, the predominantly saltwater portion of the LSJR mainstem. Data are presented as a box-and-whiskers plot with the green boxes indicating the median ±25% (middle 50% of the data) and horizontal lines indicate the median values. Blue whiskers indicate the minimum and maximum values in the data set. The dotted red horizontal line indicates the class III water quality criterion for predominantly marine waters and the dashed orange line indicates the criterion for mostly freshwaters.

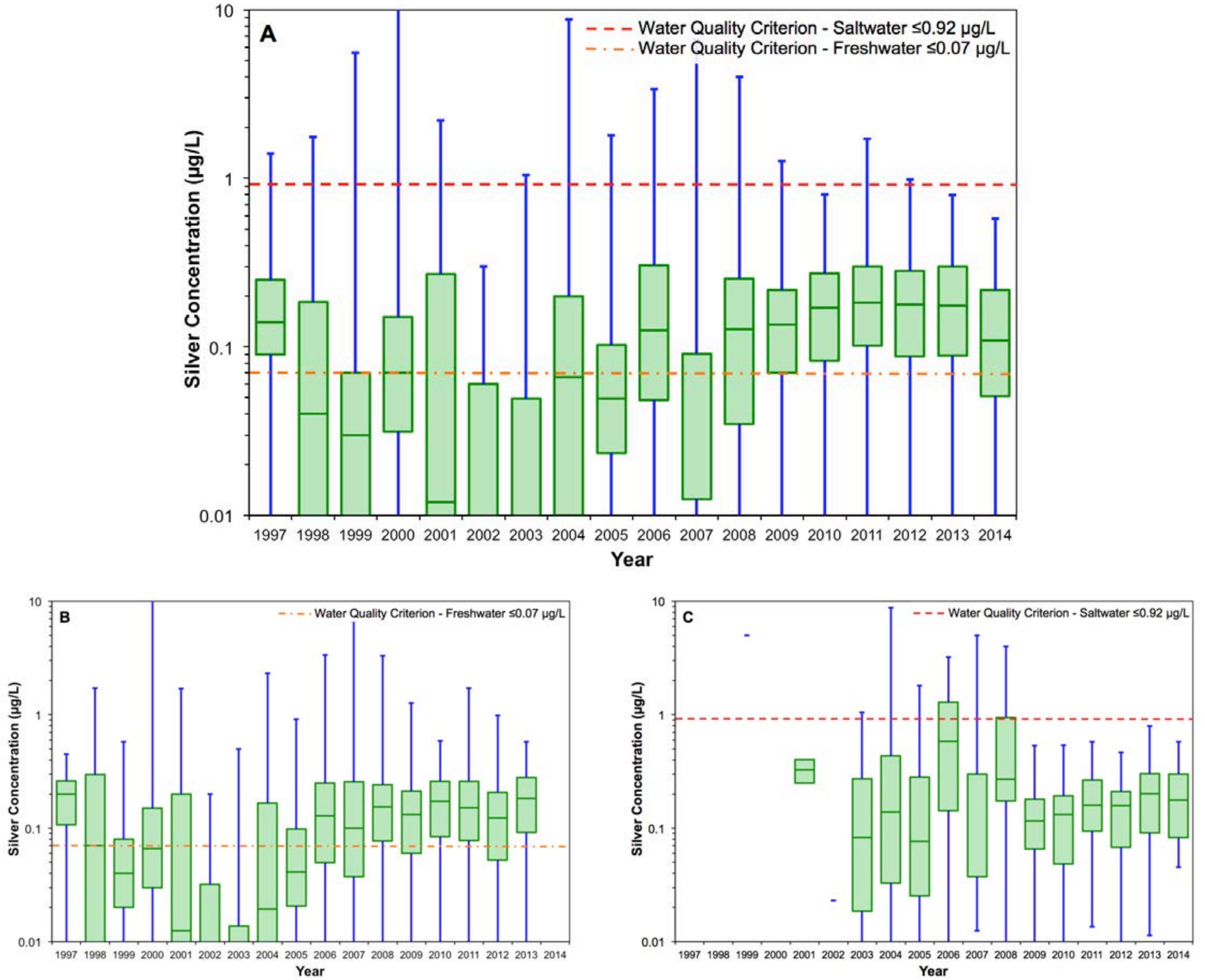


Figure 5.18 Yearly silver concentrations (μg/L) from 1997 to 2014 in A., the entire LSJR, B., the freshwater portion of the LSJR mainstem, and C, the predominantly saltwater portion of the LSJR mainstem. Data are presented as a box-and-whiskers plot with the green boxes indicating the median ±25% (middle 50% of the data) and horizontal lines indicate the median values. Blue whiskers indicate the minimum and maximum values in the data set. The dotted red horizontal line indicates the class III water quality criterion for predominantly marine waters and the dashed orange line indicates the criterion for mostly freshwaters.

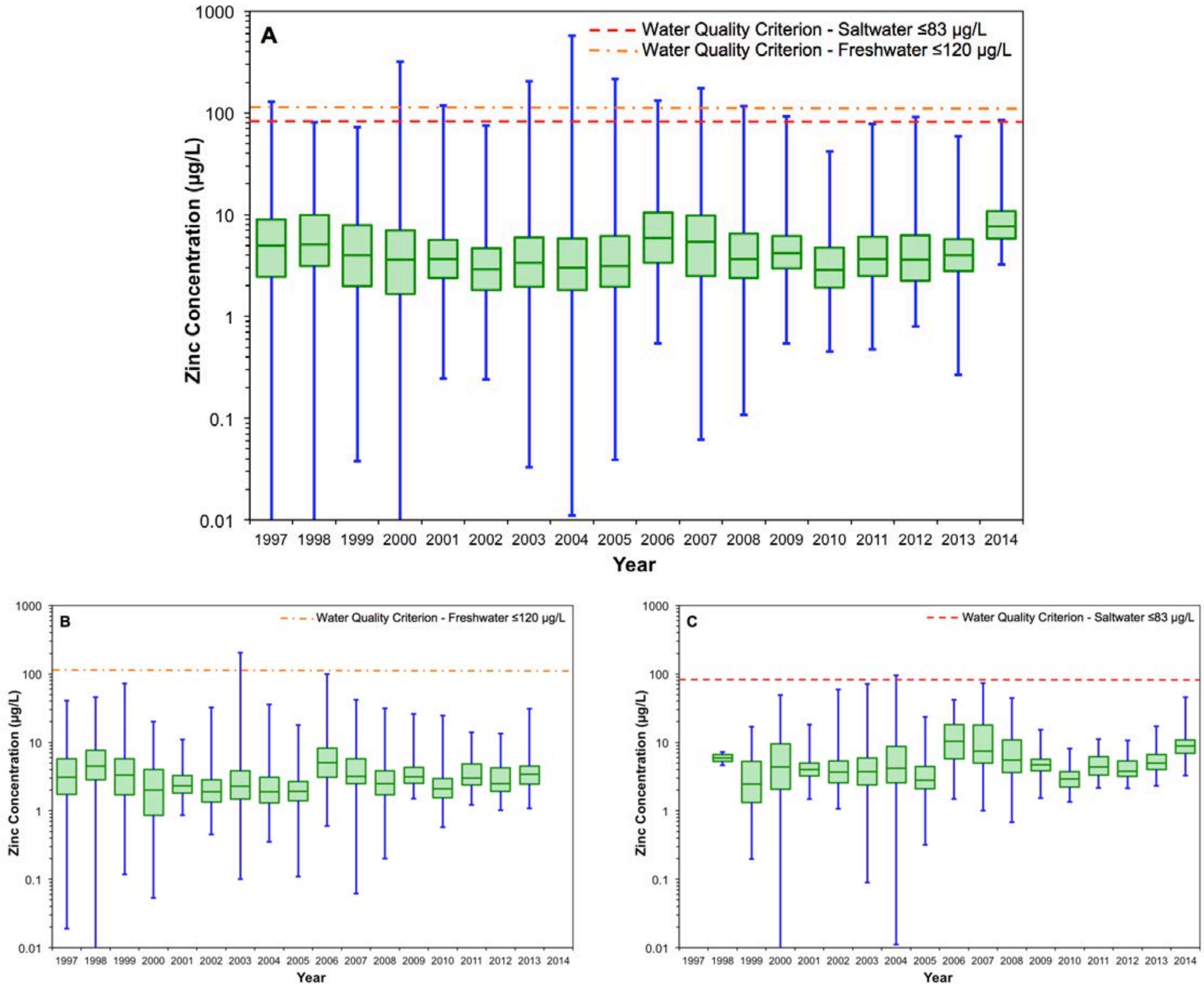
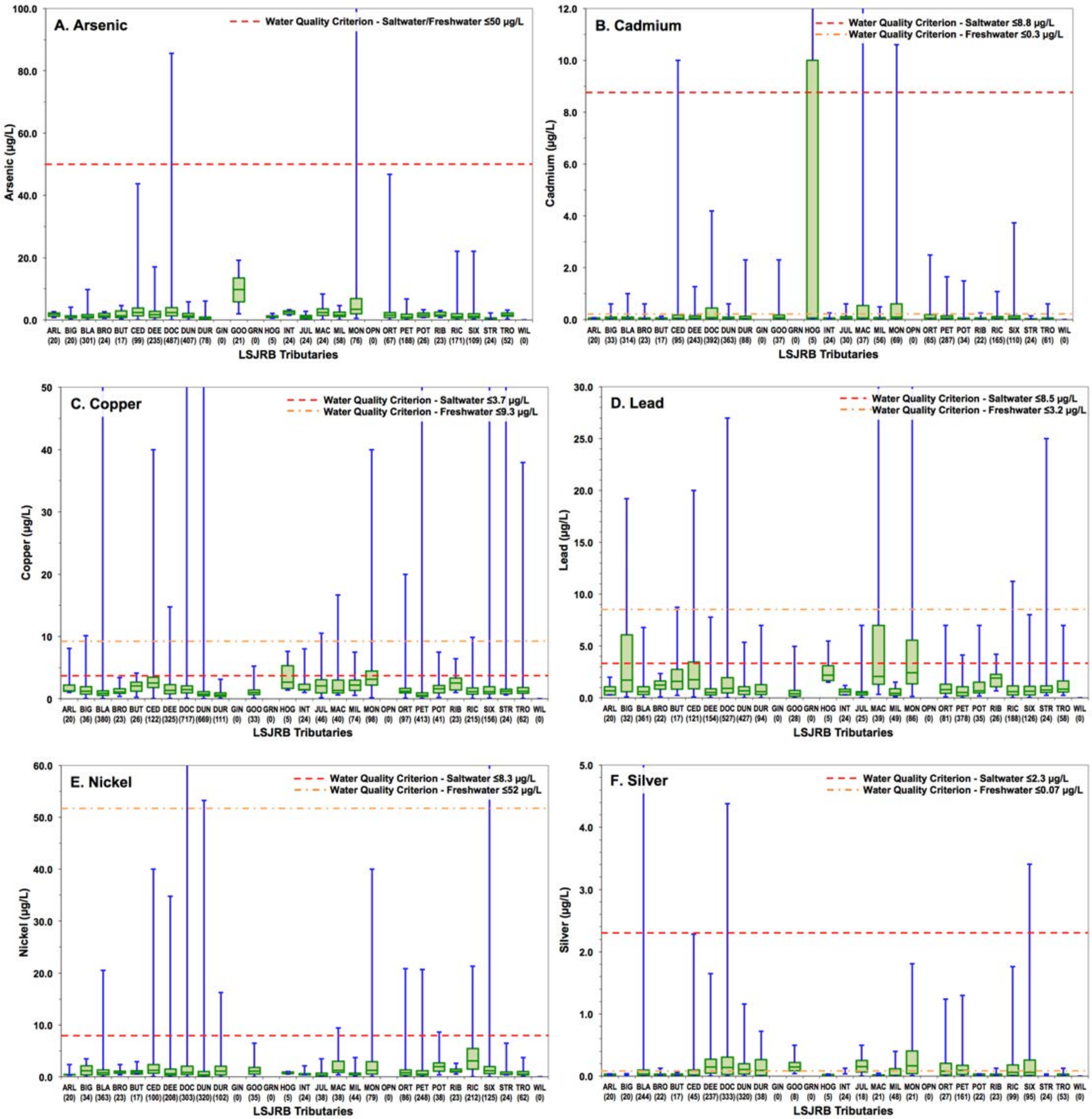
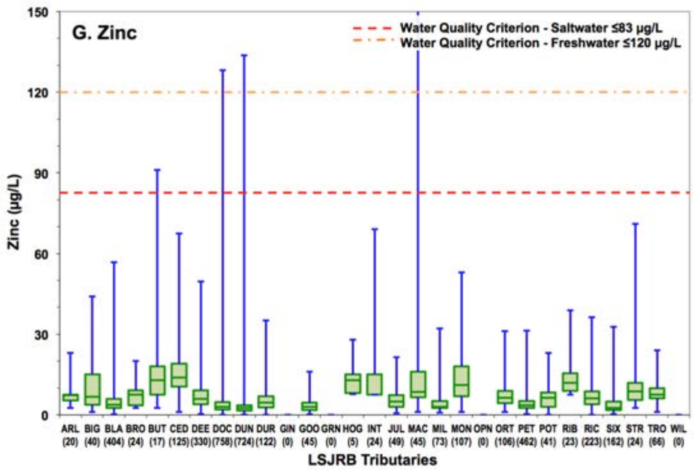


Figure 5.19 Yearly zinc concentrations (µg/L) from 1997 to 2014 in A., the entire LSJR, B., the freshwater portion of the LSJR mainstem, and C, the predominantly saltwater portion of the LSJR mainstem. Data are presented as a box-and-whiskers plot with the green boxes indicating the median ±25% (middle 50% of the data) and horizontal lines indicate the median values. Blue whiskers indicate the minimum and maximum values in the data set. The dotted red horizontal line indicates the class III water quality criterion for predominantly marine waters and the dashed orange line indicates the criterion for mostly freshwaters.


A. Arsenic
Water Quality Criterion - Saltwater/Freshwater ≤50 µg/L
Arsenic (µg/L)
B. Cadmium
Water Quality Criterion - Saltwater ≤8.8 µg/L
Water Quality Criterion - Freshwater ≤0.3 µg/L
Cadmium (µg/L)
C. Copper
Water Quality Criterion - Saltwater ≤3.7 µg/L
Water Quality Criterion - Freshwater ≤9.3 µg/L
Copper (µg/L)
D. Lead
Water Quality Criterion - Saltwater ≤8.5 µg/L
Water Quality Criterion - Freshwater ≤3.2 µg/L
Lead (µg/L)
E. Nickel
Water Quality Criterion - Saltwater ≤8.3 µg/L
Water Quality Criterion - Freshwater ≤52 µg/L
Nickel (µg/L)
F. Silver
Water Quality Criterion - Saltwater ≤2.3 µg/L
Water Quality Criterion - Freshwater ≤0.07 µg/L
Silver (µg/L)
LSJRB Tributaries



Tributary Comparison Key

ARL – Arlington River
BIG – Big Fishweir Creek
BLA – Black Creek
BRO – Broward River
BUT – Butcher Pen Creek
CED – Cedar River
DEE – Deep Creek
DOC – Doctors Lake
DUN – Dunns Creek
DUR – Durbin Creek
GIN – Ginhouse Creek
GOO – Goodbys Creek
GRN – Greenfield Creek
HOG – Hogan Creek
INT – Intracoastal
JUL – Julington Creek
MAC – McCoy Creek
MIL – Mill Creek
MON – Moncrief Creek
OPN – Open Creek
ORT – Ortega River
PET – Peters Creek
POT – Pottsburg Creek
RIB – Ribault River
RIC – Rice Creek
SIX – Sixmile Creek
STR – Strawberry Creek
TRO – Trout River
WIL – Wills Branch

Figure 5.20 Water column variation in A. arsenic, B. cadmium, C. copper, D. lead, E. nickel, F. silver, and G. zinc in over 29 tributaries of the Lower St. Johns River Basin (see key for tributary codes). Data are presented as a box-and-whiskers plot with the green boxes indicating the median ±25% (middle 50% of the data) and horizontal lines indicate the median values. Blue whiskers indicate the minimum and maximum values in the data set. The dotted red horizontal line indicates the class III water quality criterion for predominantly marine waters and the dashed orange line indicates the criterion for mostly freshwaters. Values in brackets below the tributary codes represent the number of data points for each tributary.

5.5.2.2. Metals in Sediments

The metals in sediments that we have evaluated in this study include mercury, lead, cadmium, copper, silver, zinc, and chromium. Metals in general have been elevated over natural background levels in sediments all throughout the LSJR for at least two decades and continue to do so today. Nearly all (75-91%) of the sediments that were analyzed since 2000 have had concentrations of chromium, zinc, lead, cadmium, or mercury (discussed in more detail below) that are greater than natural background levels (**NOAA 2008**), sometimes by very large amounts. Sediments in Rice Creek that were analyzed in 2002 had mercury levels that were about 100 times greater than natural background levels. High metal concentrations were found in sediments elsewhere throughout the river, including the Cedar-Ortega system, Moncrief Creek off the Trout River, Broward Creek, and Doctors Lake.

Table 5.2 Average Metal Concentrations and Percentage of Samples Exceeding Background and Sediment Quality Guidelines in the LSJR Sediments from 2000-2007[1] (see text in Section 5.2 for data sources)

	Average, ppm	Background, ppm[1]	% > Background	TEL[2], ppm	% > TEL	PEL[2], ppm	% > PEL
Copper	29	25	42%	19	50%	108	4%
Chromium	50	13	78%	52	45%	160	1%
Zinc	139	38	72%	124	47%	271	7%
Lead	45	17	65%	30	50%	112	7%
Silver	0.6	0.5	38%	0.7	20%	2	5%
Cadmium	0.6	0.3	66%	0.7	36%	4	0%
Mercury	0.1	0.1	61%	0.1	39%	0.7	1%

1 BG = Natural background concentrations (**NOAA 2008**) 2 TEL=Threshold Effects Level (sensitive species may be affected); PEL = Probable Effects Level (some species affected)

Despite some hot spots, metals in sediments are generally present at concentrations near or below their TELs. About 40% of the 2000-2007 samples exceeded TELs for one or more metals, and up to 5% exceeded the PEL. Two important contributors to overall metal toxicity, zinc in the Cedar River in Area 1, and silver in Area 2, had average concentrations between their respective TELs and PELs (Figure 5.21). These findings suggest that the metals found throughout the LSJR individually exert a low-level stress. However, taken together these metals can be an important class of stressor to the river, as indicated by a cumulative toxicity pressure greater than one (Figure 5.22).

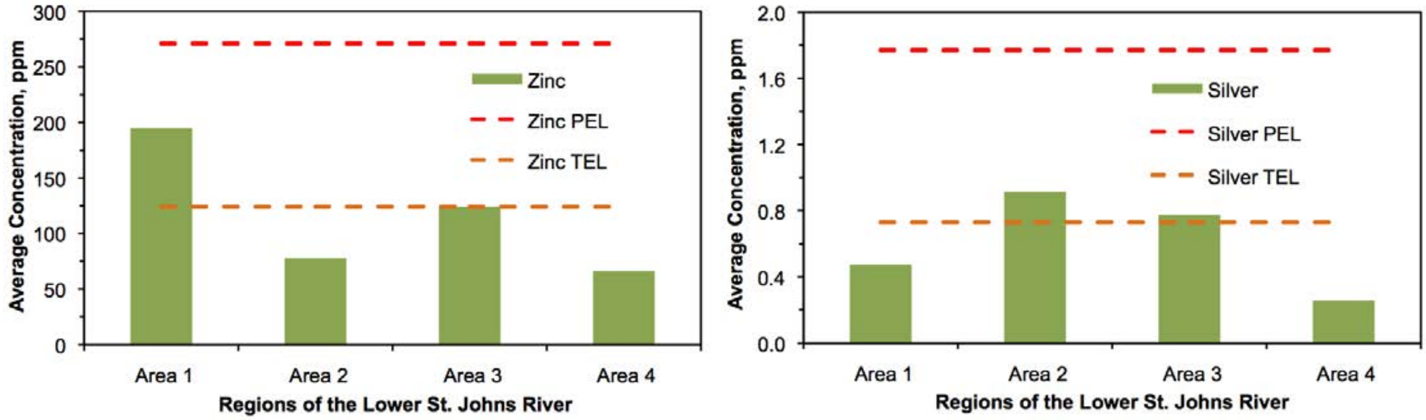


Figure 5.21 Average concentrations of zinc and silver in sediments from 2000-2007 in the four areas of the LSJR. Sediment quality guidelines for zinc and silver are shown as dashed lines. Area 1 – western tributaries; Area 2 – north arm; Area 3 – north main stem; Area 4 – south main stem. See text in Section 5.2 for data sources.

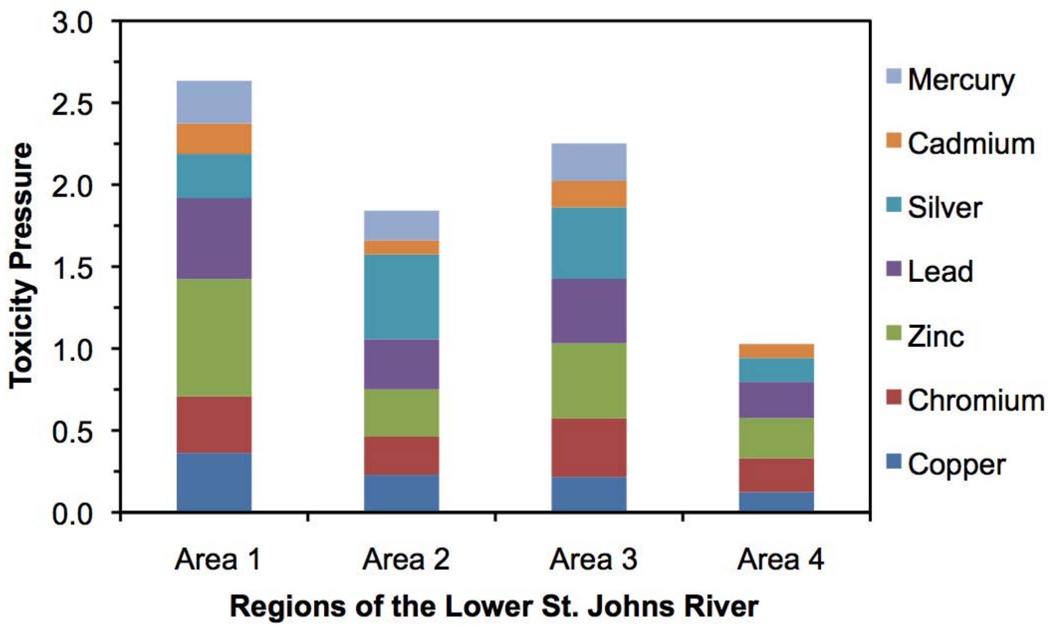


Figure 5.22 Toxicity pressure of metals in sediments from 2000-2007 in the four areas of the LSJR. Area 1 – western tributaries; Area 2 – north arm; Area 3 – north main stem; Area 4 – south main stem. Note no mercury data were available from 2000-2007 in Area 4. See text in Section 5.2 for data sources.

There is little evidence of a widespread decrease in metals between the 1980s and 2007, in contrast to the PAHs. Different metals exhibit slightly different trends with time, but none appear to be significantly declining in any area. Metals in Area 3, the north main stem, have increased since 1983, but the rate of increase has slowed since the mid-1990s (Figure 5.23). Since that time, the overall toxicity pressure from these six metals has generally remained between one and three (Figure 5.24). Although we did not see a decrease in lead concentrations from the ban of lead products from gasoline, sediment cores analyzed by other researchers give a more accurate picture of the historical record of contamination. The core studies do show recovery from lead contamination since the 1970s (**Durell, et al. 2005**).

For these reasons, the **STATUS** of metals in sediments is ***unsatisfactory*** and the **TREND** is ***unchanged***.

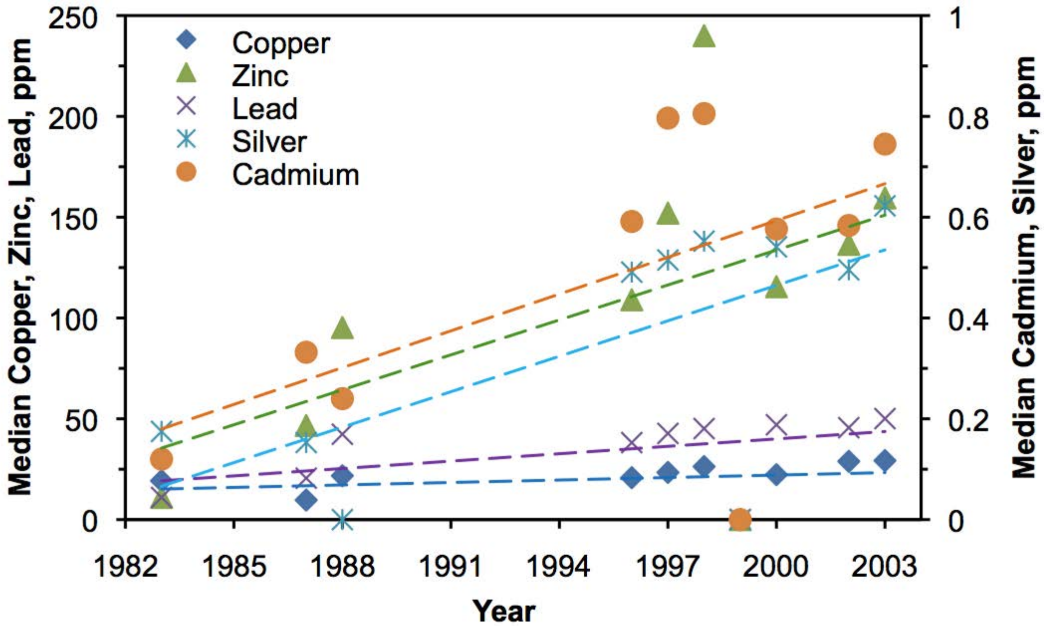


Figure 5.23 Median concentrations of copper, zinc, lead, silver, and cadmium in sediments in Area 3, the north main stem. Trend lines are shown as dashed lines. See text in Section 5.2 for data sources.

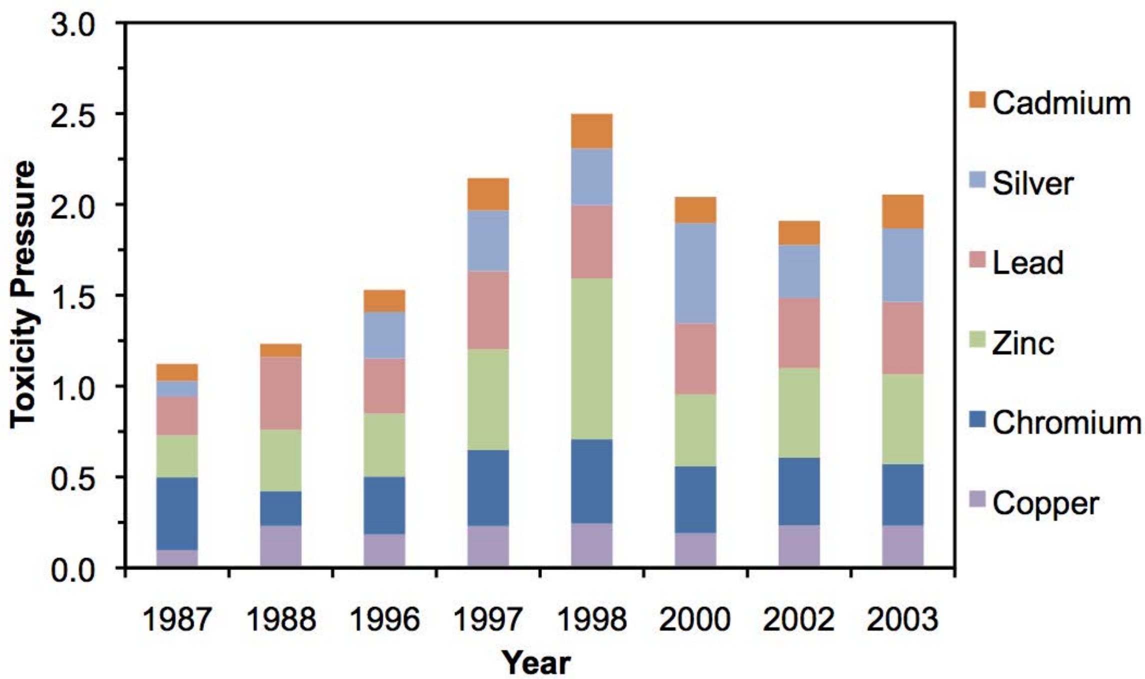


Figure 5.24 Toxicity pressure from metals in the LSJR in Area 3, north main stem. Note that years are not continuous. See text in Section 5.2 for data sources.

5.5.3. Point Sources of Metals in the LSJR Region

Most metals emitted to the atmosphere declined significantly between 2001 and 2013, with a 97% reduction in vanadium released by electric utilities accounting for much of the decline (Figures 5.25 and 5.26). In addition, zinc, nickel, copper and cobalt emissions declined significantly over a decade (Figure 5.25). In 2013, releases of 14 different metals to the atmosphere in the LSJR basin were reported. Zinc was the most abundant and comprised about 35% of all metal releases.

In contrast to atmospheric emissions, surface water discharges of metals increased by over 230% to a total of 71,000 pounds between 2001 and 2013. The paper industry released most total metals into the LSJR in 2013 because of the extremely large quantity of manganese that was reported (51,000 pounds). Additional metals discharged by that industry were lead (415 pounds) and mercury (0.26 pounds). Excluding manganese, electric utilities discharged about 50 times more metals than the paper industry and had more diverse effluents with 13 different metals. The metals released by electric utilities totaled 19,712 pounds in 2013 with the top five being barium, cobalt, molybdenum, nickel, and zinc.

Much of the overall increase in metals released to the LSJR is due to the electric utilities, which has had an increase of 250% in its metal discharges since 2001, despite that industry's significant reduction in its air emissions (Figures 5.27 and 5.28). Seven of the 13 metals that were reported in 2013 by the utilities have higher release rates than in 2001. Zinc and nickel increased sharply between 2011 and 2012, while cobalt and barium increased significantly between 2007 and 2008 and have steadily increased since. Reported discharges of mercury and vanadium have decreased since 2001.

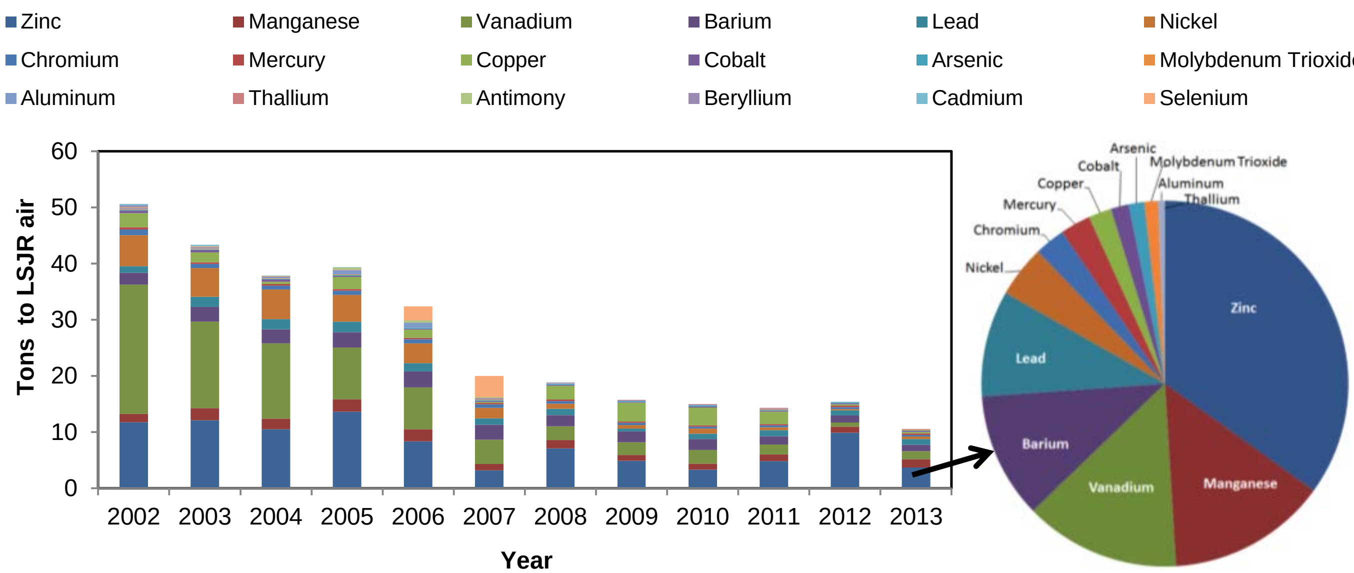


Figure 5.25 Trends and status of 18 metals released into the atmosphere of the nine-county LSJR region as reported in the Toxics Release Inventory **EPA 2015c***). Inset shows the distribution of 10 tons of metals emitted in 2013.*

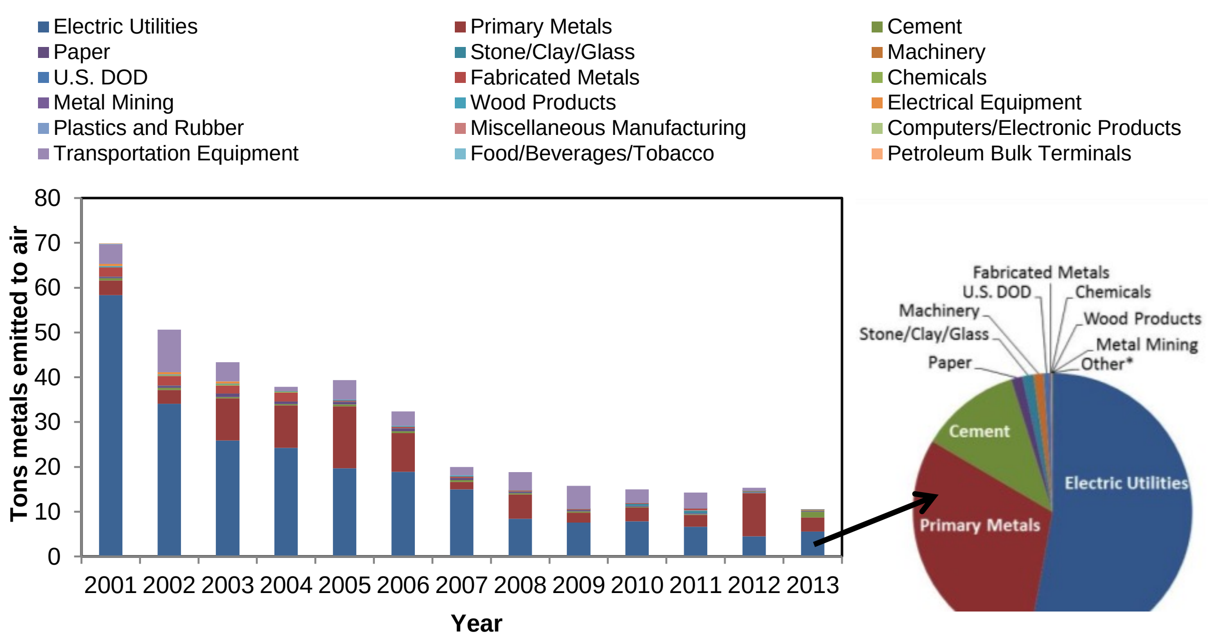


*Figure 5.26 Trends and status of 18 industries releasing metals into the atmosphere of the nine-county LSJR region as reported in the Toxics Release Inventory (***EPA 2015c***). Inset shows the major industries emitting 10 tons of metals in 2013. Other* industries consist of electrical equipment, plastics and rubber, computers/electronic products, and miscellaneous manufacturing which together emitted 4 pounds of metals in 2013.*

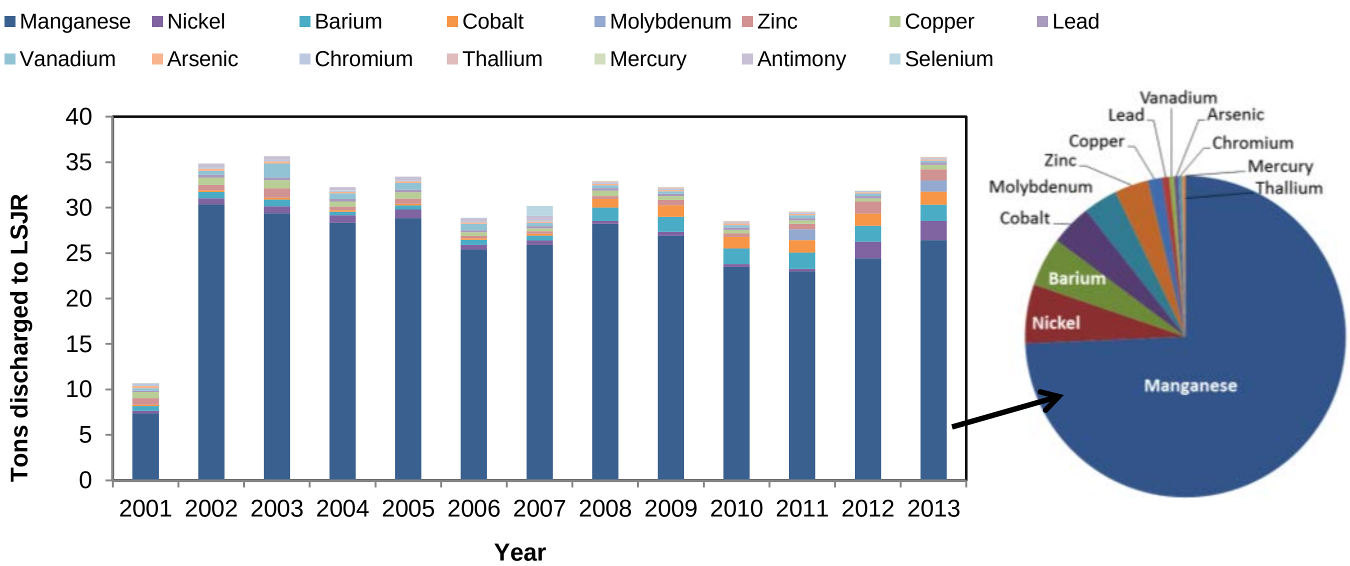


*Figure 5.27 Trends and status of 15 metals released to the LSJR and its tributaries as reported in the Toxics Release Inventory (**EPA 2015c**). Inset shows the distribution of 71,000 pounds of metals discharged in 2013.*

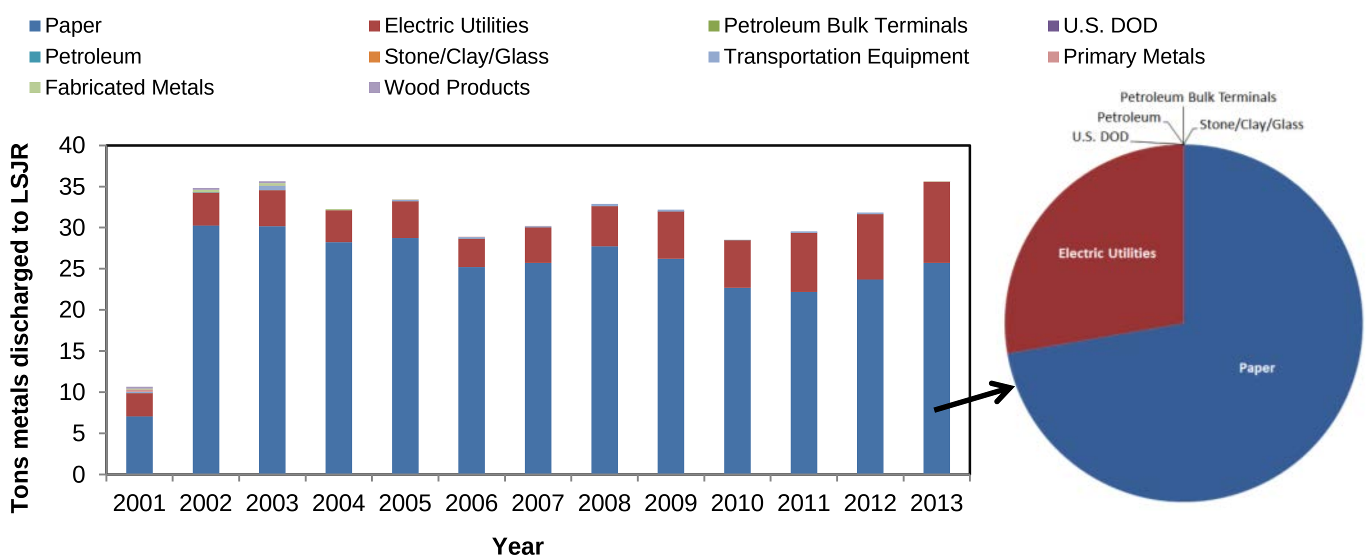


*Figure 5.28 Trends and status of 10 industries releasing metals into the LSJR and its tributaries as reported in the Toxics Release Inventory (**EPA 2015c**). Inset shows the major industries discharging 71,000 pounds of metals in 2013.*

5.5.4. Mercury in the LSJR

5.5.4.1. Background: Mercury

Like most metals, mercury has natural and anthropogenic sources. As a constituent of the earth's crust, it is released to the atmosphere by natural geologic processes. However, anthropogenic activities can substantially increase the mobilization of mercury into the atmosphere. In an assessment of national sources of mercury, EPA determined that approximately 60% of the mercury deposited in the US had anthropogenic sources (**EPA 1997b**). Though there is evidence there is more mercury in the atmosphere since the Industrial Revolution, there is little certainty about trends since that time (**EPA 1997a**).

People introduce mercury into the atmosphere by fuel combustion, ore mining, cement manufacture, solid waste incineration, or other industrial activities. Fertilizers, fungicides, and municipal solid waste also contribute to mercury loading but combustion is the primary anthropogenic source (Figure 5.29).

The LSJR emissions reflect national trends in that most waste mercury is emitted from coal power plants (**EPA 1997a**).

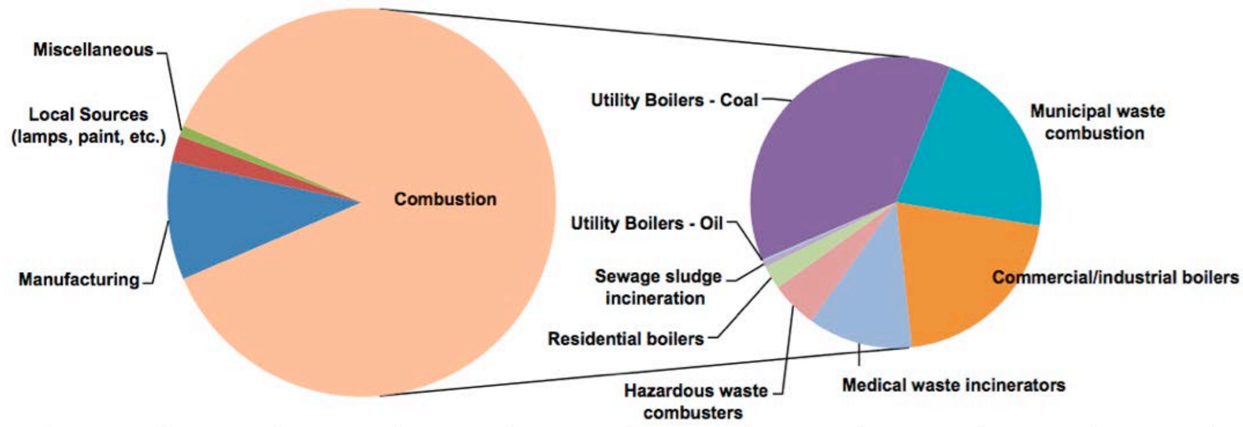


*Figure 5.29 National emissions of mercury in the US totaled 158 tons in 1994-1995. Combustion is responsible for the large majority (left graph) with coal combustion the most important type (right graph) (**EPA 1997a**).*

When mercury is released to the atmosphere, the most common type of release (**EPA 1997a**), its fate is highly dependent on the form of the mercury, meteorological conditions, and the location of the source. Elemental gaseous mercury Hg^0, is the most abundant in the atmosphere and stays there for long periods of time. Oxidized species, Hg II forms, are more water-soluble and are washed out of the atmosphere and are readily transported to rivers and streams. Local and regional modeling of the fate of mercury indicates that a substantial portion of emitted mercury travels farther than 50 km from the original source (**EPA 1997a**). Consequently it is extremely difficult to isolate specific sources of mercury to a particular watershed. Considerable effort at the federal and state level has been devoted to understanding how mercury travels and cycles throughout the globe.

Once deposited into an aquatic environment, mercury can be transformed by microorganisms to an organic form, methyl mercury. Methyl mercury production is promoted by low nutrients, low oxygen, and high dissolved organic carbon levels which are typical of many Floridian lakes, blackwater streams, and wetlands. Methyl mercury binds to proteins in tissue and therefore readily bioaccumulates. All of the mercury present in prey fish is transferred to predators and the mercury biomagnifies in organisms as it travels up the food chain. High level predators with long life-spans, such as largemouth bass in freshwater and king mackerel in marine systems, accumulate the most mercury in their tissue and therefore they generally have the highest concentrations (**Adams and McMichael Jr 2001; Adams, et al. 2003**). Humans, as top predators, consume mercury in fish also and this is the route by which most people are exposed to mercury (**EPA 2001**). It is important to realize that when anthropogenic mercury is mobilized to the atmosphere, it will continue to cycle, in some form, through the atmosphere, water bodies, land, or organisms (Figure 5.30).

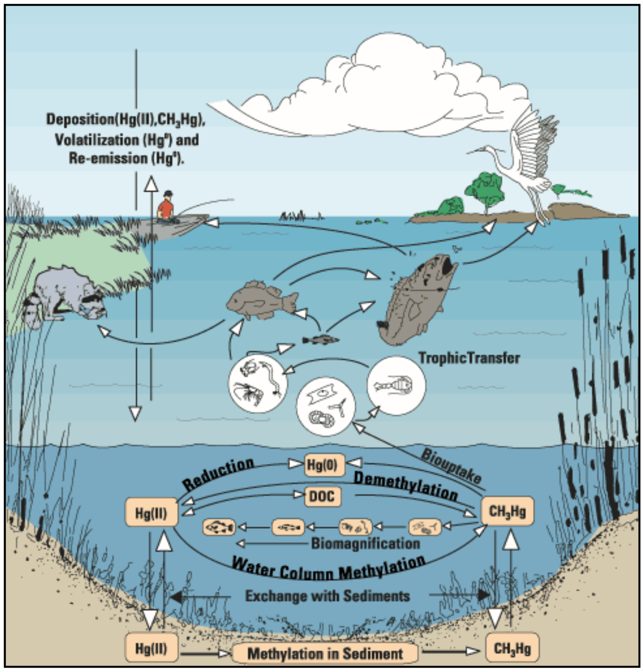


Figure 5.30. The mercury cycle. Mathematical models must accurately describe each step to predict the effect of mercury sources on fish tissue. Source: ***USGS 2004****.*

The human health effect of mercury depends on the form, the mode of exposure, and the concentration. Methyl mercury is particularly worrisome because it is the form that is most toxic, it is most easily absorbed through the human gastrointestinal tract and it is released to the bloodstream after consumption. It passes readily into most tissues, including the brain and kidneys, where it can cause permanent damage. Exposure to pregnant women is particularly hazardous since it is passed from mothers to their children through the placenta before birth, and through nursing after birth. Methyl mercury is a neurotoxin and its effect on developing fetus' and children is of high concern. It also appears to affect cardiovascular and immunological health of all human populations. High levels of the metallic form of mercury (Hg0) also cause problems but inorganic salts of mercury (Hg II) do not pass as easily into the brain so neural damage is not as certain (**ATSDR 2000**, **EPA 2001**).

Both EPA and FDEP have begun to evaluate the significance of mercury contamination in water bodies based on human health risks from fish consumption, rather than based on simple water column concentrations (**EPA 2001**, **DEP 2009a**, **FDOH 2015**). As discussed in Section 3 of this report and below, when mercury is found in fish or shellfish, health agencies may limit consumption, particularly for women of childbearing age and children. There are 16 fresh water bodies in the LSJR basin for which the FDOH has placed consumption limits for some fish species because of mercury (**FDOH 2015**), as indicated in Appendix 3.1.3. In addition, there were 34 water bodies or segments of water bodies listed as impaired in the 2009 303(d) list for TMDL development based on health effects from consumption of fish contaminated with mercury (**DEP 2009a**) (see Section 1 and Appendix 1 D).

A methyl mercury fish tissue criterion has been developed that is designed to protect the health of general and sensitive populations while allowing people to consume as much fish as possible (**EPA 2001**, **ATSDR 1999**). Sensitive populations consist of children and women of childbearing age. To determine if mercury found in fish is harmful to human health, toxicologists use a reference dose (a dose that causes no ill effect) of 0.0001 mg mercury/kg human body weight per day for sensitive populations, and 0.0003 mg mercury/kg human body weight per day for the general population. These are the amounts of mercury that can be safely consumed. When fish tissue exceeds safe levels, FDOH, in concert with FWC and FDEP, issues advisories that recommend limiting consumption to a certain number of meals per week or month, or restricting it entirely. Meals should be limited for the general population when mercury in fish tissue exceeds 0.3 ppm and when it exceeds 0.1 ppm for sensitive populations. When fish tissue exceeds 1.5 ppm, the general population should not eat any of the fish. Sensitive populations should not eat any fish with mercury concentrations greater than 0.85 ppm. (**EPA 2001**, **Goff 2010**). As long as monitored fish contain low enough concentrations of mercury so that people will not consume more than the reference dose at standard rates of consumption, then no restrictions will apply.

The FL DEP issued its final report for the statewide mercury TMDL in October 2013 (see Section 1 in this report for additional information on TMDLs). The ultimate goal of the TMDL effort is to reduce the levels of mercury in fish in State waterways to safe levels where fish consumption advisories have been issued. The elements of the multi-year study to establish mercury load limits included measuring the amount of mercury that is present in Florida waterways (in fish, water and sediment), and identifying sources and fates of mercury in the State through atmospheric monitoring and modeling.

Intensive monitoring of atmospheric mercury, along with other metals and air quality parameters, was undertaken at seven sites from 2008-2010. Wet deposition of mercury was monitored at all sites and in Jacksonville, Pensacola, Tampa and Davie dry deposition was also monitored. In addition to atmospheric monitoring, extensive analysis of mercury in fish, primarily largemouth bass, and water quality was undertaken in over 100 freshwater lakes and 100 streams. The selected sites varied in acidity, trophic status and color, all parameters that were thought to affect the fate of mercury in water bodies and its uptake by fish and other organisms. These data are being used to predict levels in unmonitored sites. Mathematical models of the emissions, transport, and rates of deposition of mercury into waterways were developed as well as models to predict the concentrations in fish with different mercury loading rates and in different aquatic environments, Estimating exposure to mercury by different populations and establishing a safe level of consumption was another significant effort in the project (**DEP 2007a; DEP 2011a; DEP 2013a**). Results of the studies indicate that the vast majority of the man-made sources of mercury in Florida waters has global sources and that aquatic lakes and streams vary more because of their geochemistry than because of atmospheric loading. The TMDL report indicates significant reductions in mercury emissions have occurred in the last two decades.

No additional reductions will be required of local coal fired power plants due to recent large reductions arising from federal regulation (**EPA 2013d**) and the global nature of the sources in State waters. NPDES permit-holders will have no additional mercury limits imposed beyond currently enforced water quality criteria because of the limited impact of local atmospheric and point sources, and because of anticipated impending EPA regulations (**EPA 2015a**).

5.5.4.2. Current and Future: Mercury in LSJR Sediments

The influx of information about mercury sources and levels that will arise from the TMDL process will provide much needed information about the extent of the contamination throughout the state. In the LSJR, there is some mercury information but the amount of data is limited. For example, there is no information for the south main stem, Area 4, for recent years and other areas in the LSJRB have limited numbers of samples. In addition, changes in standard methods of analysis make it difficult to track trends. The mercury database will be improved with the mercury TMDL process and future river status reports will summarize the results of that regulatory action.

Sites where mercury has been analyzed in sediments over the years are shown in Figure 5.31, and the results of those analyses are given in Table 5.3. The distribution of mercury, the TEL, PEL, and hot spots in various years is shown in Figure 5.32. Mercury levels that exceed natural background levels and the most protective environmental guidelines are found throughout the main stem. There are isolated locations in the LSJR, particularly in Rice Creek and the Cedar-Ortega system, where mercury occurs at concentrations high enough to impair the health of organisms. It is possible that mercury will bioaccumulate in those fish, crabs, and shellfish that spend most of their lives at these highly contaminated sites.

It should be noted that the toxicity pressure reflects the overall toxicological stress on the ecosystems of the river. It does not address human toxicity, which arises when we consume toxic metals that have found their way into the environment, via contaminated biota. Human health effects are discussed in the following section.

Because of the high degree of toxicity pressure due to mercury, the high numbers of sites that have mercury in sediments greater than background levels, and the high degree of potential human risk, the **STATUS** of mercury in sediments is ***unsatisfactory*** and the **TREND** is ***unchanged***.

Table 5.3 Average Mercury Concentrations and Percentage of Samples Exceeding Background and Sediment Quality Guidelines in the LSJR Sediments (see text in Section 5.2 for data sources)

Mercury	1983	1988	1996	1997	1998	1999	2000	2002	2003	2007
Average Conc., ppm	0.5	0.1	0.3	0.2	0.6	0.2	0.2	0.1	0.1	0.1
No. of Samples	13	28	143	52	214	40	45	28	25	16
% > BG[1]	15%	64%	80%	77%	95%	80%	67%	71%	76%	38%
% > TEL[2]	15%	32%	63%	75%	75%	53%	36%	39%	48%	38%
% > PEL[2]	15%	0%	6%	0%	30%	8%	2%	0%	0%	0%

BG = Natural background concentrations (**NOAA 2008**) TEL=Threshold Effects Level (sensitive species may be affected); PEL = Probable Effects Level (some species affected)

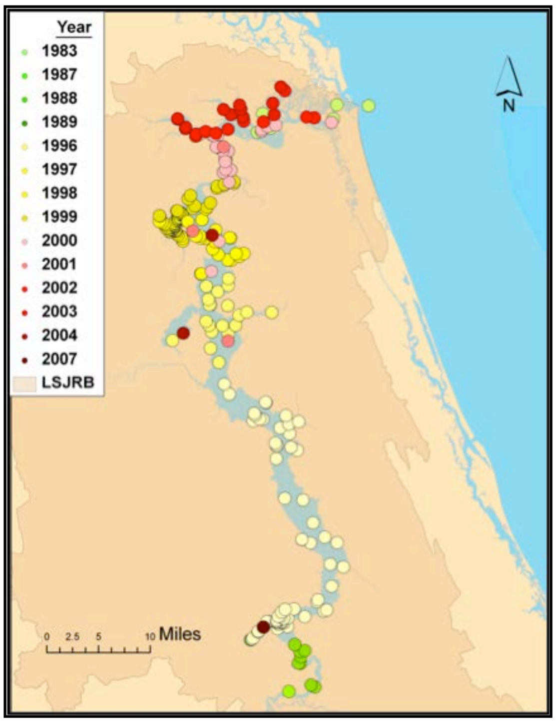


Figure 5.31 Mercury sediment sample sites.

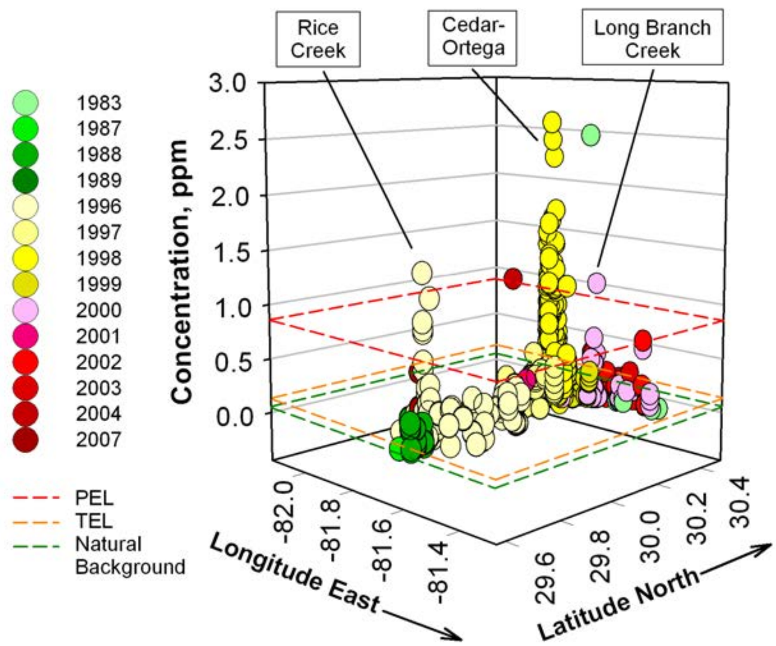


Figure 5.32 Mercury Sediment Quality Guidelines and LSJR sediment hot spots (scale of mercury concentrations does not show Rice Creek 2007 maxima). See text in Section 5.2 for data sources.

5.5.4.3. Mercury in LSJR Fish and Shellfish

The diverse types of fish that live in the LSJR were reviewed in Section 3 in this report. As noted, there is considerable overlap of freshwater, estuarine, and marine species in the dynamic LSJR system. In the following data sets, the marine and estuarine species associated with the LSJR were caught north of Doctors Lake. Of the marine and estuarine species discussed, King mackerel, Spanish mackerel, gag grouper, and bull shark are generally found offshore, while the others reside largely in coastal and estuarine waters. The freshwater species were caught south of Doctors Lake. The species that are reported are considered important because of their economic significance. Some species are also closely monitored because they are at high risk for elevated concentrations due to their large size and trophic status (**Adams, et al. 2003**).

As shown in Figure 5.33, most species in the northern marine section of the LSJR, had low levels of mercury in their tissue, including blue crabs and oysters. The only data that exceeded FDOH's most restrictive advisory levels for the general population were those reported in the Section 303(d) Impaired Waters listing for mercury, as indicated in Figure 5.31. Those data, collected throughout Florida's coastal and offshore waters, resulted in impaired designations for the marine and estuarine main stem and seven tributaries north of Doctors Lake. The King mackerel and bull shark, top predator species that are large and long-lived, have significantly elevated levels compared to the other species. Levels in marine/estuarine species in the LSJR are comparable to or less than the averages for the individual species for the entire State of Florida (**Adams, et al. 2003**). However, as discussed in Section 3, advisories have been issued for all Florida coastal waters for numerous species including Atlantic croaker, dolphin, gag grouper, King mackerel, sharks, red drum, southern flounder, spotted seatrout, and southern kingfish (**FDOH 2015**). Additional information about consumption advisories is available in Section 3 of this report.

In the fresh portions of the river south of Doctors Lake, the main stem, tributaries, and large connected lakes, fish have been extensively sampled in the last 10 years (Figure 5.34). Levels exceeding the 0.3 mg/kg fish tissue criterion have been found primarily for largemouth bass, which caused the southern part of the LSJR main stem, Lake Broward, and Crescent Lake to be designated as impaired. Not included in this discussion are several smaller, isolated southern lakes that have been listed as impaired due to elevated concentrations of mercury, again primarily in largemouth bass. As with the LSJR marine and estuarine fish, LSJR freshwater fish mercury levels are generally comparable to the rest of the state. Furthermore, the 1998-2005 national average for largemouth bass was 0.46 ppm, which is similar to LSJR values (**Scudder, et al. 2009**).

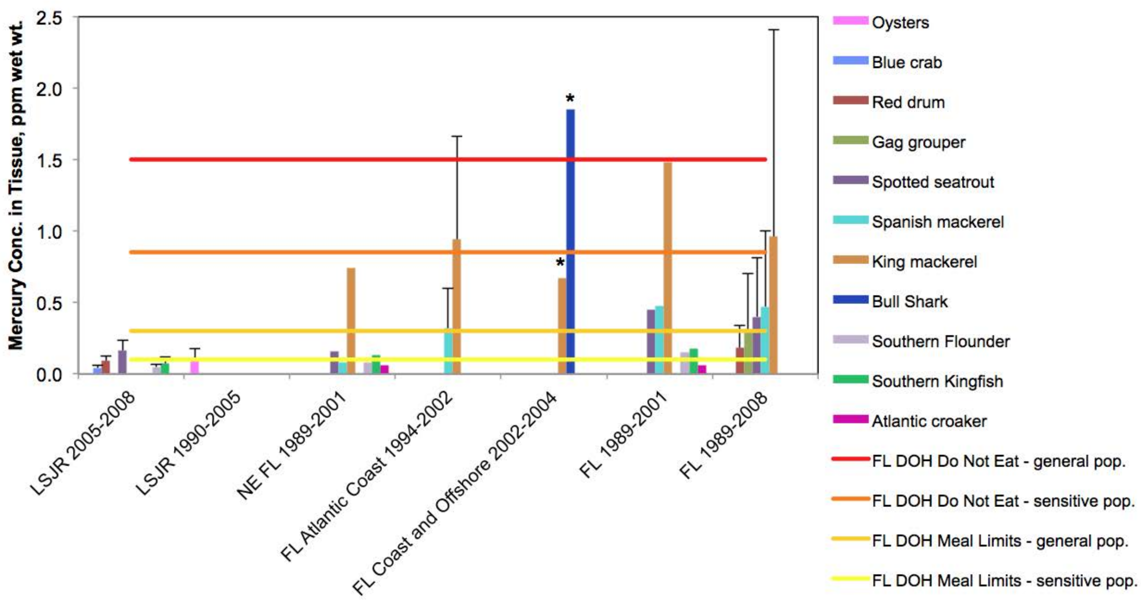


*Figure 5.33 Average mercury concentrations in estuarine and marine invertebrates and fish caught in coastal waters, offshore, and in the LSJR north of Doctors Lake. An asterisk means the data set was used for 2009 303(d) impaired water listing for the marine/estuarine main stem and 7 tributaries north of Doctors Lake. Standard deviation bars are shown. Data sources include **Adams and McMichael Jr 2007; Adams, et al. 2003; Axelrad 2010; Brodie 2008; Goff 2010; NOAA 2007b**. Numbers of fish and available variance information are given in Appendix 5.12.*

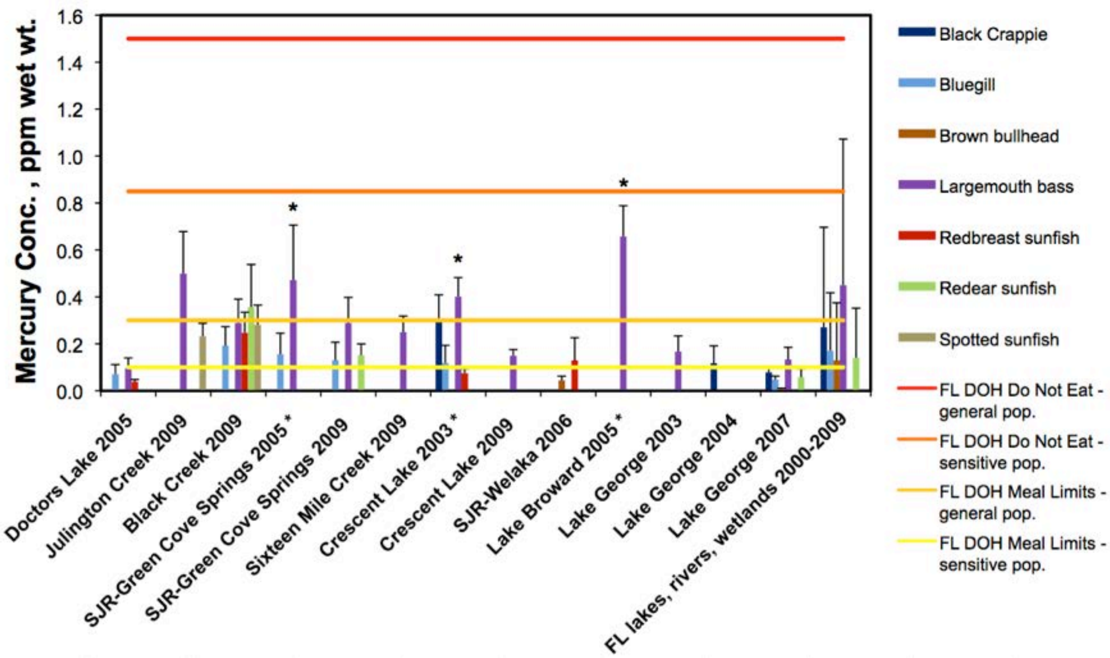


*Figure 5.34 Average mercury concentrations in freshwater fish caught in the LSJR main stem and tributaries south of Doctors Lake, as well as other Florida waterways. An asterisk means the data set was used for 2009 303(d) impaired water listing for the indicated water bodies in the LSJRB. Data sources include **Axelrad 2010; Goff 2010; Lange 2010**. Numbers of fish and available variance information are given in Appendix 5.12.*

There are a number of consumption advisories due to mercury contamination in fish in the LSJR region, and most fish contain at least small amounts of mercury. However, high levels of mercury in fish are found mostly in the top predators and in only a few of the fresh water bodies sampled. By consuming mostly lower-level predators and smaller, short-lived fish species (e.g., Atlantic croaker, flounder, sunfish) people can benefit from this healthy food source with minimal risk.

5.5.4.4. Point Sources of Mercury in the LSJR Region

In 2013, 558 pounds of atmospheric mercury emissions in the LSJR region were from four primary industries, including stone/clay/glass (30)%, electric utilities (30%), primary metals (25%), and cement (15%). Emissions from gypsum and steel production have grown since 2008, offsetting reductions by the electric utility industry (Figure 5.35). St. Johns River Power Plant and Northside Generating Station reduced their mercury emissions by 71% between 2001 and 2013 (Figure 5.35). While 10 facilities reported mercury emissions, five were responsible for 99% of total atmospheric mercury emissions in 2013 (Figure 5.36).

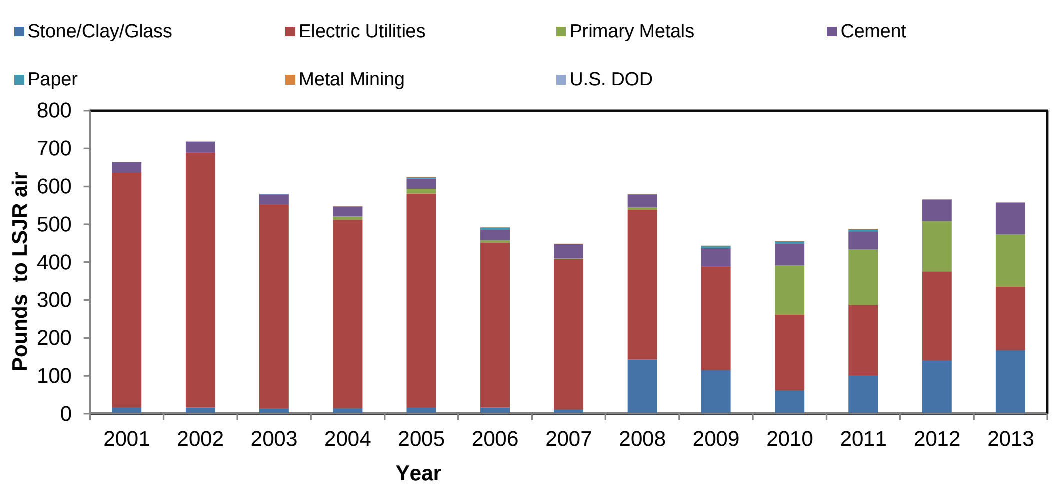


*Figure 5.35 Trends and status of emissions of mercury into the atmosphere of the nine-county LSJR basin by industry as reported in the Toxics Release Inventory (**EPA 2015c**).*

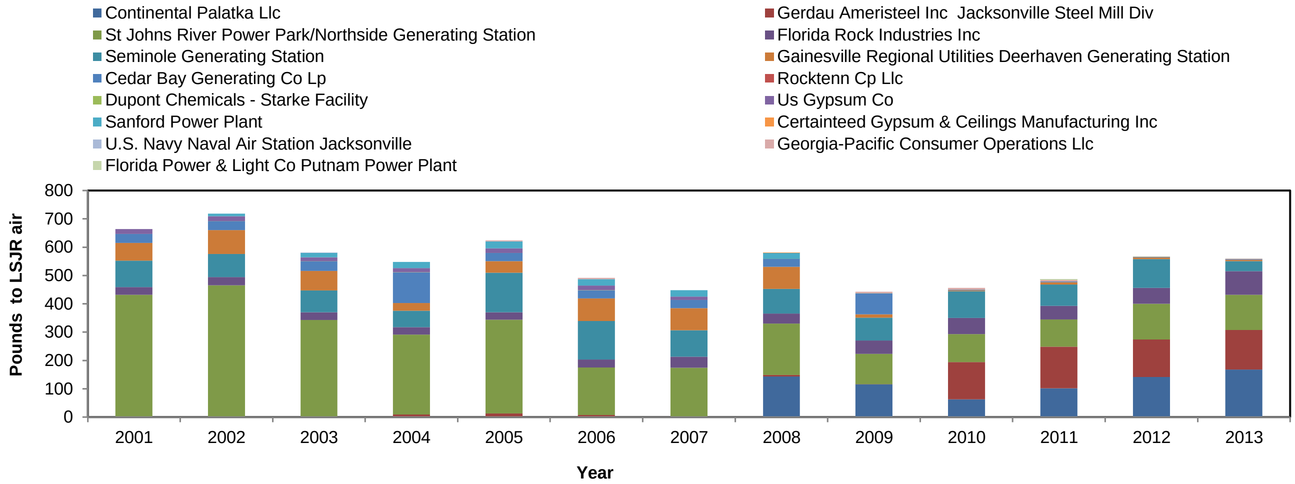


*Figure 5.36 Trends and status of emissions of mercury into the atmosphere of the nine-county LSJR basin by the facilities (**EPA 2015c**).*

Mercury releases into the LSJR and tributaries significantly dropped in 2004 with Seminole Generating station dramatically reducing its output of mercury. Coincident with reductions in atmospheric emissions since 2006, St. Johns River Power Park and Northside Generating Station steadily increased their discharges of mercury into surface water until 2011. However, in the subsequent two years there was a dramatic decrease in mercury discharges by that facility. Total discharges of mercury into the LSJR have been reduced by nearly 75% since 2001 (Figure 5.37). The RSEI model of chronic human health toxicity indicates that mercury releases to water by Seminole Electric is among the top potential risks compared to all releases in the region (**EPA 2013c**). However, we are unable to fully assess the importance of mercury because St. Johns River Power Park/Northside Generating Station, a major discharger, is not included in the RSEI modeling (see Section 5.3).

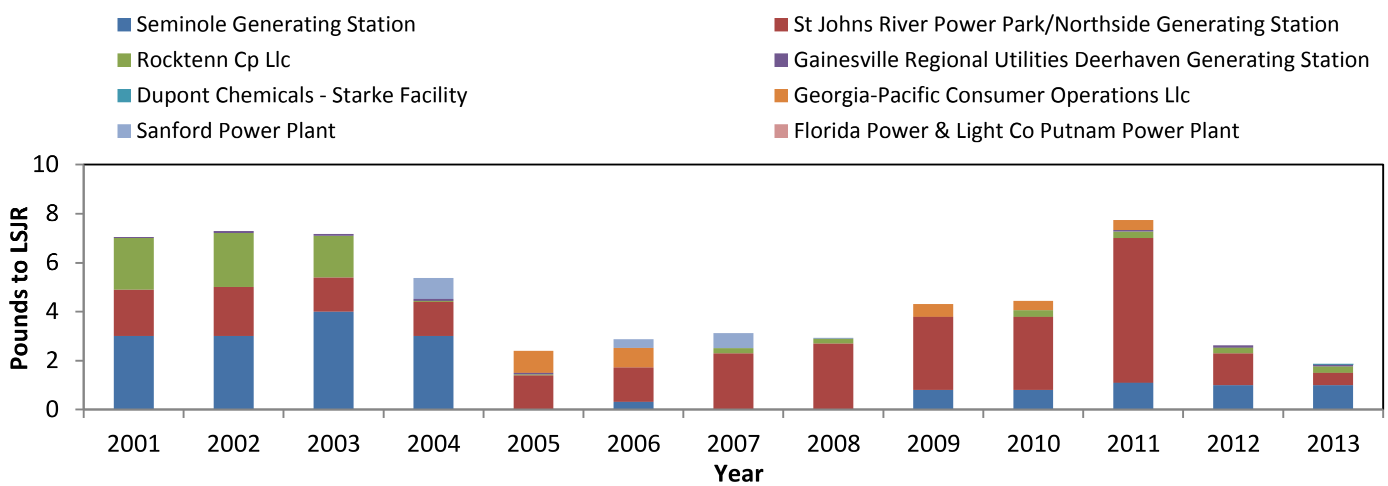


*Figure 5.37 Trends and status of discharges of mercury into the LSJR and its tributaries by facility as reported by the Toxics Release Inventory (**EPA 2015c**).*

5.6. Polychlorinated Biphenyls (PCBs)

5.6.1. Background and Sources: PCBs

Polychlorinated biphenyls, PCBs, are synthetic chemical mixtures that were used for their nonflammable and insulating properties until they were restricted in the U.S. in the 1970s. They provided temperature control in transformers and capacitors, and were also used for lubrication and other heat transfer applications. They were sold primarily under the name of Arochlors in the U.S. They are still found in old fluorescent lighting fixtures, appliances containing pre-1977 PCB capacitors, and old hydraulic oil. The characteristics of the fluids were changed by modifying the mixture components, so each of the major Arochlor formulations is composed of different concentrations and combinations of the 209 PCB chemicals. Until the mid 1970s, PCBs were also used in manufacturing processes for a wide range of different substances, from plastics to paint additives. By 1979, the manufacture of PCBs in the U.S. was prohibited and their import, use, and disposal, were regulated by EPA (**EPA 1979**). One of the most visible PCB legacies in the U.S. is the Hudson River, where capacitor plants discharged wastewaters into the river resulting in contaminated sediments in rivers and estuaries for decades to come.

PCBs are inert, which makes them industrially valuable but environmentally harmful. They do not react readily by microbes, sunlight, or by other typical degradation pathways. They are not very soluble in water, so the lighter ones tend to evaporate and the heavier ones tend to associate with particles, whether in the air, soil or sediments. Another important consequence of PCBs' chemical properties is that they are compatible with fatty tissue, allowing extensive uptake and bioaccumulation in the fats of plants and animals. They are readily biomagnified because they are not easily metabolized and excreted.

PCBs are introduced directly into the environment today primarily from hazardous waste sites and improper disposal of old appliances and oils. However, they also may be transported long distances in the atmosphere, either in gas form or attached to particles. The principal route of PCB transport to aquatic environments is from waste stream waters, downstream movement by means of solution and re-adsorption onto particles, and the transport of sediment itself, until eventually reaching estuaries and coastal waters. Like PAHs, sometimes sources of PCB contamination can be elucidated by examining different patterns of contamination of the different PCB constituents, but several processes obscure those patterns. Weathering, currents and tides, multiple sources in a large drainage basin, and repeated cycles of evaporation, sorption and deposition all tend to mix everything up so individual sources are not usually identifiable unless there is a very specific, current source.

Because of methodological developments over the years and variable definitions of "total PCBs", it is not feasible to compare total PCB or mixture concentrations (like Arochlors). Consequently, several individual PCBs were evaluated here and total PCBs were estimated from those values. The specific eight PCBs we decided to evaluate were selected on the basis of their presence in the LSJR and on the availability of comparable data. We estimate that the PCBs we examined in this study represent 20% of the total PCBs that were actually present. More information about the calculations we used to estimate total PCBs is given in Appendix 5.3.A.

5.6.2. Fate: PCBs

PCBs have a high affinity for suspended solids (organic matter) and are very insoluble in water. Due to their properties, PCBs are found in much higher concentrations in sediment and biota than in water. Sediment can become a significant source as well, because of desorption, diffusion, and possible re-suspension of PCBs in the water column. Removing contaminated sediments is the predominant mechanism of PCB removal.

5.6.3. Toxicity: PCBs

The effects of PCBs on wildlife as a result of waterway contamination have been extensively documented over the years. During the 1960s, mink farmers in the Great Lakes region fed their mink fish from Lake Michigan tributaries that had been contaminated with PCBs. These ranch mink suffered severe outcomes including high mortality rates and reproductive failure. PCB contamination in the Hudson River from 1947-1977 by the General Electric Company led to fishing bans that were not changed until 1995 when fishing became permissible on a catch-and-release basis only. The state of New York recommends that children under age 15 and pregnant women not eat any fish from the 200-mile stretch of the river that has been designated as an EPA Superfund site.

PCBs can bioaccumulate in the fat tissue of organisms since they are highly lipophilic (**Cailleaud, et al. 2009; Fisk, et al. 2001**) and can also be directly toxic to aquatic organisms. **Cailleaud, et al. 2009** reported a preferential accumulation of HMW PCBs and preferential elimination of LMW PCBs in an estuarine copepod. Unlike PAHs, PCBs can biomagnify up the food chain and top-level carnivores are particularly susceptible to toxicity (**Guillette Jr., et al. 1999**). Since PCBs are chemically inert, they are highly resistant to chemical breakdown and are therefore very persistent in the environment. **Sepúlveda, et al. 2002** reported the accumulation of PCBs in the livers of Florida largemouth bass collected from different locations in the LSJR. The liver PCB concentrations were highest in the largemouth bass collected from Green Cove and Julington Creek, as compared with those collected from Welaka. PCBs exert toxicity in aquatic organisms primarily via endocrine disruption and neurotoxicity (**Fossi and Marsili 2003**). Reported effects of PCB exposure include male feminization due to increased estradiol, reduced male and female fertility, modified immune system, and altered reproductive behavior. Acute toxicity values (96 h LC50s) range from 12 µg/L to 10 mg/L for aquatic invertebrates and range from 8 µg/L to 100 mg/L for fish. **Bergeron, et al. 1994** demonstrated an increased percentage of female hatchling turtles after exposure of the eggs to PCBs in the laboratory. Likewise, **Guillette Jr., et al. 1999** reported reproductive abnormalities in the hatchling and juvenile alligators of Lake Apopka, FL, thought to have been caused by embryonic exposure to PCBs and other environmental contaminants. However, **Sepulveda, et al. 2004** also recently reported thiamine deficiency in Florida alligators as another potential cause of the population declines.

Due to their endocrine-disrupting properties, PCBs may threaten aquatic ecosystems at both the individual and the population level.

5.6.4. Current Status: PCBs in Sediments

Polychlorinated biphenyls are produced only by human activity so their simple presence denotes human impact. The majority of the sediments contained some PCBs. Specifically; 84-100% of sediment samples collected from 1996 to 2003 in the four river regions contained PCBs. Most had levels that could affect sensitive species, as indicated by concentrations greater than TEL guidelines (Figure 5.38). However, in most of the river, the estimated total PCB concentrations were far below the probable effects level of 189 ppm, producing a low toxicity pressure throughout the basin. The PCBs were often found at levels typical for urban, industrialized environments (**Daskalakis and O'Connor 1995**). Most of the river's sediments had concentrations of PCBs well below the 80 ppb that characterizes a "high" level compared to the rest of the coastal areas in the country (**Durell, et al. 2004**).

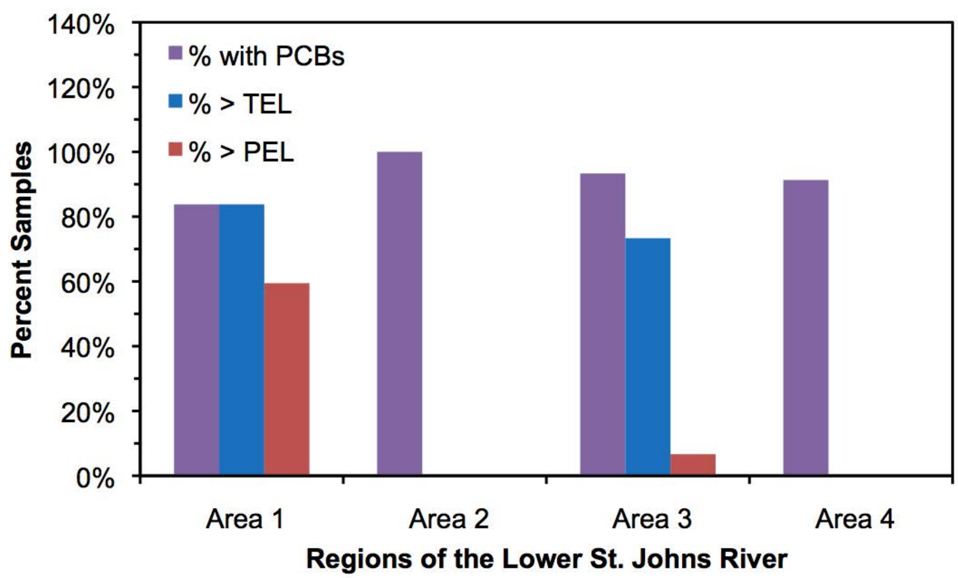


Figure 5.38 Percentage of sediment samples from 2000-2007 that contain PCBs and have PCBs concentrations that exceed Threshold Effects Levels (TEL) and Probable Effects Levels (PEL) for PCBs. See text in Section 5.2 for data sources.

The picture changes somewhat when we partition the river. It becomes apparent that the western tributaries, Area 1, have far more toxicity pressure from PCBs than the main stem portions of the river. In Cedar River and Rice Creek, the average PCB concentration exceeded, by a factor of ten, the concentrations that are considered high for the nation's coastal areas (**Daskalakis and O'Connor 1995**). Particularly high levels were found in the Cedar-Ortega in the late 1990s. In 2000-2003, Rice Creek was a hot spot for PCBs 105, 118, 128, 180 and 206, the first two of which are among the most toxic (**ATSDR 2000**) (Figure 5.39).

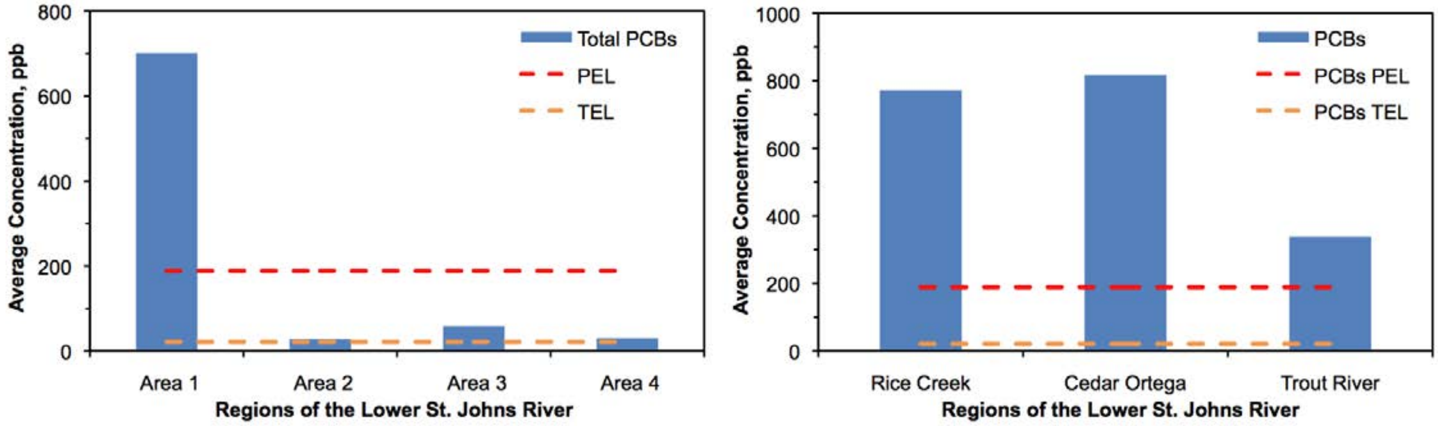


Figure 5.39 Average concentrations of PCBs in sediments from 2000-2007 in the four areas of the LSJR and in three streams in Area 1. Sediment quality guidelines for PCBs are shown as dashed lines. Area 1 – western tributaries; Area 2 – north arm; Area 3 – north main stem; Area 4 – south main stem. See text in Section 5.2 for data sources.

5.6.5. Trends: PCBs in Sediments

There are data only for 1996-2003 for PCBs, so trends are difficult to identify. However, the distributions of the PCBs we examined appear to be reasonably constant along the river and across the years, an outcome of the persistence of the long-banned substances.

5.6.6. Summary: PCBs

PCBs persist in the LSJR long after regulatory and environmental controls were put into place. They are weathering but continue to exert their influence, with little discernable changes in concentration over time. Outside of the highly contaminated western tributaries, Area 1, these compounds by themselves are not likely to be major stressors of benthic organisms, but may exert a low-level toxicity pressure throughout the basin. For these reasons, the **STATUS** of PCBs in sediments is ***unsatisfactory*** and the **TREND** is ***unchanged***."

5.7. Pesticides

5.7.1. Background and Sources: Pesticides

Pesticides are diverse, primarily including insecticides, herbicides, fungicides and rodenticides. Pesticides enter water bodies from a number of different pathways. They are applied directly to control aquatic nuisances such as water hyacinth. They can be components of runoff from residential, agricultural, and other commercial applications. They also come from the atmosphere, usually attached to particles. As a consequence, pesticides are widespread in residential, urban, and agricultural areas. Pesticides are very different in their chemistry and environmental fate, in large part because pests are also diverse. Target species include mold, bacteria, rats, spiders, barnacles, mosquitoes and more, and each species has a metabolism that is vulnerable to different chemicals.

Pesticide manufacture and use has evolved significantly towards protecting the environment since the times when lead and arsenic compounds were dusted in homes to control insects (**Baird 1995**). Efforts have been made to create pesticides that can specifically target the pest and that can degrade after their function has been performed. However, pesticides that were used historically continue to be environmentally important because of their persistence.

Organochlorine compounds (OC's; molecules containing carbon and chlorine) were introduced in the 1930s and bear some similarity to PCBs in their characteristics and environmental fate. They were effective for long periods of time against insects in homes, institutions, crops, and livestock, largely because they were nearly non-degradable. Because of their longevity, these compounds remain in the environment today despite being regulated and removed from manufacture up to forty years ago. Several organochlorine compounds and their degradation products are the focus of this review because of their environmental significance and the availability of historic data.

It is important in the future to also evaluate pesticides currently used, which tend to be less persistent but more toxic. The varied land uses in the LSJR basin, along with its extensive recreational and commercial maritime activities, cause a broad spectrum of pesticides to be loaded into the river. The U.S. Army Corps of Engineers directly applies herbicides 2,4-D, diquat, and glyphosate in the southern parts of the river for the control of water hyacinths and water lettuce (**USACE 2012**). The city of Jacksonville sprays malathion, organophosphates, and pyrethroids for mosquito control (**COJ 2010**). Agriculture in southern LSJR contributes to the pesticide load as well. While estimates of current total pesticide loading rates into the LSJR are elusive, it is reasonable to suppose that some of the most commonly detected pesticides in agricultural, residential, and urban U.S. streams (**Gilliom, et al. 2006**) will be present in the LSJRB. These include the herbicides atrazine, metolachlor, simazine, and prometon, as well as the insecticides diazinon, chlorpyrifos, carbaryl, and malathion. Finally, the tributyl tins used by the maritime industry should be reviewed. These common pesticides represent 11 different classes of chemical structures that will have very different fates and impacts on the environment.

In this study, four organochlorine pesticides and their primary degradation products were assessed. These compounds were primarily used as insecticides and removed from market in the 1970s. Aldrin was used against termites and other insects in urban areas. Dieldrin is a degradation product of aldrin, and was also used directly against termites. Endrin targeted insects and rodents, usually in agriculture, and endrin aldehyde is its degradation product. Heptachlor and its degradation product, heptachlor epoxide, are used here as markers for chlordane contamination since the complex chlordane mixtures are difficult to compare across years and analytical methods. Chlordanes were used in agriculture and in households, especially for termite control. Finally, the notorious insecticide dichlorodiphenyltrichloroethane (DDT) and its degradation products, dichlorodiphenyldichloroethylene (DDE) and dichlorodiphenyldichloroethane (DDD) are also reviewed.

5.7.2. Fate: Pesticides

OCs such as DDT, aldrin, dieldrin, endrin, chlordane, and benzene hexachloride exhibit low volatility, chemical stability, lipid solubility, and a slow rate of biotransformation and degradation. In many cases, the biotransformation products inside the organism could exhibit similar toxicity as the original parent chemical; such is the case for DDT and its biotransformed metabolites, DDE and DDD. This class of insecticides proved to be highly effective and persistent, which was ideal for remediating target pests, but resulted in very long term environmental impacts. These chemicals also have broad spectrum toxicity, meaning they can affect a variety of species, including non-target species. Additionally, like PCBs they can biomagnify up the food chain and resist chemical breakdown in the environment (**Woodwell, et al. 1967**). Because of their chemical structure, OCs primarily partition into the fat tissue of biota and primarily the organic fraction of sediment. A biomagnification assessment in the Carmans River Estuary demonstrated significant biomagnification of DDT up the food chain (**Woodwell, et al. 1967**). During its peak use, DDT led to a decline in populations of several bird species, such as the bald eagle and the peregrine falcon.

After the ban of OCs, anticholinesterase insecticides such as organophosphates (OPs) and carbamate esters (CEs) were primarily used. This class of insecticides undergoes extensive biotransformation and is therefore considered nonpersistent, relative to the earlier insecticides. These insecticides are water soluble and can remain in the water column and/or can be taken up by organic matter such as plants and animals. **Karen, et al. 1998** reported the removal of the OP insecticide, chlorpyrifos, from the water column and accumulation in the plant, *Elodea densa*, after a two-week period.

Pyrethroids are the newest (1980s) major class of insecticide accounting for one third of the world's pesticide application, and are derived from the extract of dried pyrethrum or chrysanthemum flowers. Pyrethroid use has increased with the declining use of OPs (**Baskaran, et al. 1999**). Although, pyrethroids are more hydrophobic than OPs, they only minimally accumulate in the environment and do not biomagnify (**Phillips, et al. 2010**). Pyrethroids do, however, quickly adsorb to sediment when they enter the aquatic environment (**Miyamoto and Matsuo 1990**). Benthic organisms that inhabit the sediment and porewater may be more at risk for exposure to pyrethroids than pelagic organisms.

5.7.3. Toxicity: Pesticides

Due to their prevalence in the LSJR and toxicity, this review will focus on insecticides. Insecticides generally act as neurotoxicants (poison nervous system) to aquatic organisms, although the toxic mechanisms differ between classes (**Karami-Mohajeri and Abdollahi 2011**). OCs, such as DDT, mainly affect sodium channels in the axons of nerve cells, causing them to remain open for longer than normal (**Karami-Mohajeri and Abdollahi 2011**). This results in continual excitability of the nervous tissue. In addition to damage to the nervous system, OCs have also caused reproductive effects in exposed organisms. Since Lake Apopka, FL became polluted with difocol and DDT from various sources, including a pesticide spill in 1980 and agricultural and urban runoff, the wildlife inhabiting the area has suffered severe effects. Due to the biomagnification capabilities of these contaminants, animals at the top of the food chain were most affected. Alligator populations declined due to adverse reproductive outcomes, such as reduced phallus size in males, abnormal ovarian morphology in females, modified sex steroid concentrations in both sexes, and reduced hatching success in alligator eggs (**Guillette Jr., et al. 1999; Guillette Jr., et al. 1994**). Similar effects have been observed in juvenile alligators from another Florida lake, Lake Okeechobee as well (**Crain, et al. 1998**). Further, **Rauschenberger, et al. 2004** suggested that yolk OC burdens were predictive of maternal tissue burdens and that some OCs are maternally transferred in the American alligator. After exposure to the OC insecticides, methoxychlor and DDE, accumulation of the contaminants in the ovaries of female bass and an inhibition of sex steroids were reported (**Borgert, et al. 2004**). DDT and other chlorinated pesticides were found in the livers of largemouth bass collected from the LSJR (**Sepúlveda, et al. 2002**). **Gelsleichter, et al. 2006** reported an elevated liver OC concentration in the livers of stingrays collected from Lake Jesup, in the SJR. Further, they concluded that stingray reproduction was still occurring; however, elevated serum steroid concentrations and white blood cell counts were noted, suggesting that endocrine and immune function may be altered.

The anticholinesterase insecticides have a reduced mammalian toxicity, as compared to OCs. They act by inhibiting acetylcholinesterase, which is the enzyme that destroys acetylcholine, resulting in continual stimulation of electrical activity in the nervous system. OPs are generally more effective than CEs, but they also have been shown to affect more non-target organisms. **Karen, et al. 2001** reported a significant decrease in brain acetylcholine activity and vertebral yield strength in the estuarine fish, *Fundulus heteroclitus* (commonly found in the LSJR) after exposure to environmentally relevant concentrations (in many areas) of the OP insecticide, chlorpyrifos.

Pyrethroids have an extremely low toxicity to birds and mammals and are less susceptible to biotransformation when ingested; however, they are very toxic to invertebrates and fish. As compared to the other insecticides, they are more specific in the species they target, including a range of household, veterinary, and post-harvest storage insects; and only few chronic effects have been reported as a result of exposure. The primary site of pyrethroid toxicity is the sodium channels in the nerve membrane (**Gordon 1997**), resulting in repetitive neuronal discharge (similar to DDT). The sodium channels are modified by either preventing inactivation or enhancing activation of the sodium channel when it is at rest (**Zlotkin 1999**). This action of pyrethroids results in paralysis, collapse, and inhibition of the righting reflex (**Moskowitz, et al. 1994**). Secondary toxicity to aquatic organisms, such as blue-gill and fathead minnow, has been reported, including disruption of ion regulation at the gill and decreased respiration (**Bradbury and Coats 1989**). The amphipod, *Hyalella azteca* has been shown to be extremely sensitive to pyrethroids (**Ding, et al. 2010**), possibly due to their high lipid content, and thus greater ability to store pyrethroids, relative to other organisms (**Katagi 2010**).

More toxicological data is needed to discern the effects of the contaminants in the LSJR on the organisms that reside there. The water chemistry in the river could modify the toxicity of many of the contaminants present. However, in many instances more than one type of contaminant has been shown to simultaneously occur. The degree to which exposure to elevated concentrations of multiple contaminants may affect aquatic life in the LSJR is unknown. It is clear that contaminant accumulation has occurred in several species inhabiting the LSJR, therefore the possibility of deleterious effects remains.

5.7.4. Status and Trends: Pesticides in Sediments

Organochlorine pesticides have been found all throughout the LSJR sediments for years (Figure 5.40), an expected outcome given their history of use and persistence. Like PCBs, pesticides were most prevalent in Area 1, the western tributaries, which contained the most sediments with concentrations that exceeded the pesticide PELs. However, the overall detection rate, exceedance rate, and pesticide toxicity pressure is much less than that of the PCBs. Even in the western tributaries, the toxicity quotient was less than one, and in the rest of the river, cumulative toxicity pressure from organochlorine pesticides is fairly minimal with a toxicity quotient close to 0.2. The organochlorine pesticide most responsible for toxicity pressure in the river is DDD, a degradation product of DDT, but in some years and regions, heptachlor and dieldrin were also important (Figure 5.41).

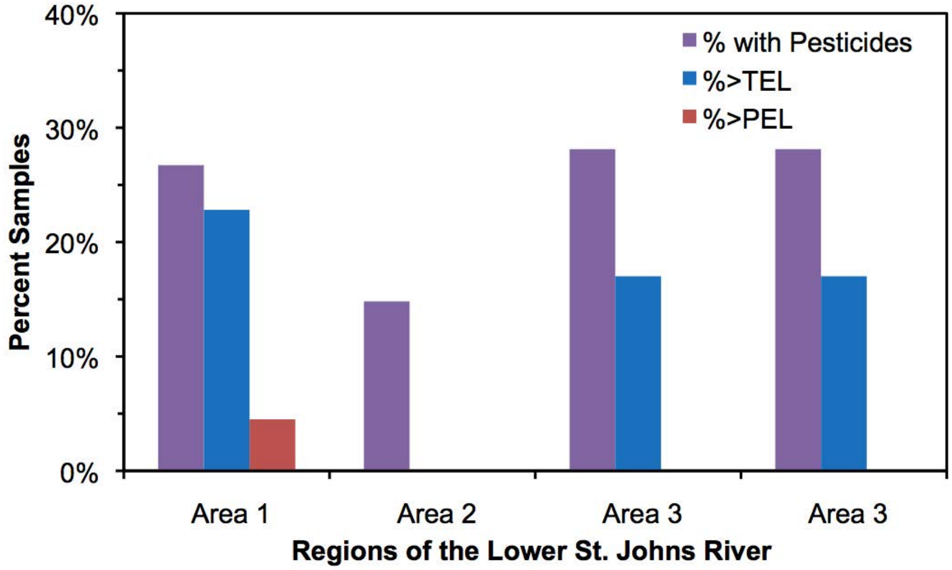


Figure 5.40 Percentage of sediment samples from 2000-2007 that contain organochlorine pesticides and have concentrations that exceed Threshold Effects Levels (TEL) and Probable Effects Levels (PEL) for one or more pesticides. Area 1 – western tributaries; Area 2 – north arm; Area 3 – north main stem; Area 4 – south main stem. See text in Section 5.2 for data sources.

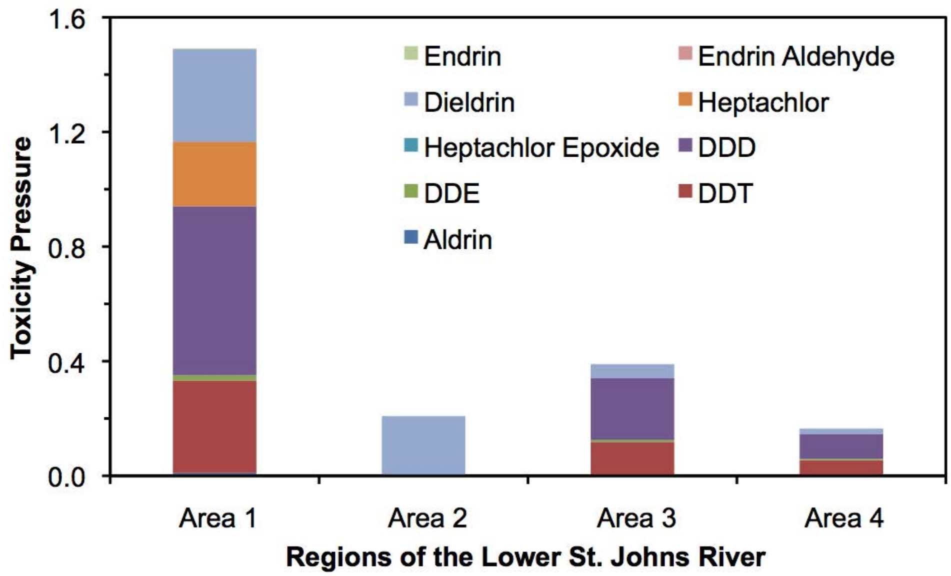


Figure 5.41 Toxicity pressure from different organochlorine pesticides and their degradation products. Area 1 – western tributaries; Area 2 – north arm; Area 3 – north main stem; Area 4 – south main stem. See text in Section 5.2 for data sources.

5.7.5. *Summary: Pesticides*

Organochlorine pesticides are present in the LSJR sediments, mostly at levels that might not cause significant adverse impacts on the benthic ecosystems, but that may add to the overall toxic burden of sensitive organisms. As with many other contaminants, the Cedar-Ortega system is the most contaminated area (**Ouyang, et al. 2003**. The DDT compounds were found most frequently and at the highest levels, compared to the other organochlorine pesticides. They exerted the most toxic pressure, though dieldrin and heptachlor were also significant in recent years. For these reasons, the **STATUS** of organochlorine pesticides in sediments is ***unsatisfactory*** while the **TREND** is ***unchanged***.

5.8. Conclusions

The history of compromised sediment quality in the LSJR from industrial and urban activities continues today in many of the downstream regions of the river (Figure 5.42). Some contaminants, such as organochlorine pesticides and PCBs, are legacies of past misjudgments, but they continue to plague the river by their persistence in the sediments. Other contaminants, such as PAHs, are common byproducts of modern urban life and the shipping industry, though the LSJR may still suffer from PAHs from past mishandling of creosote. Metals are pervasive throughout the basin sediments at levels substantially above what is considered natural background levels and there is no sign that concentrations are diminishing. Overall, the downstream LSJR basin contaminant levels are similar to other large, industrialized, urban rivers. However, upstream in Area 4, the extent of contamination appears less, with no samples that exceeded toxicity standards, but there is also less data about that region so the status is uncertain. Reductions in emissions and discharges of PAHs and metals reported by many industries since 2001 may lead to lower levels of contaminants in the LSJR system in the future.

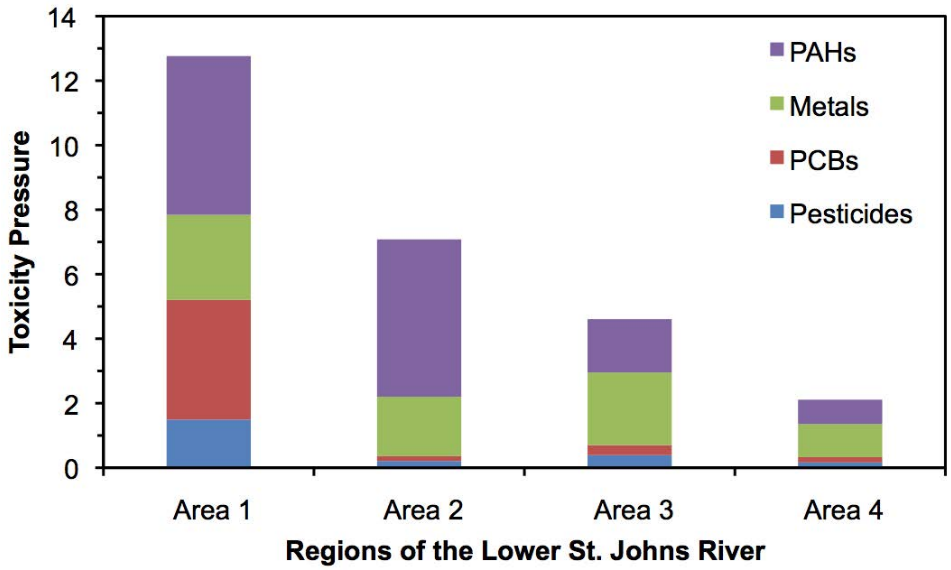


Figure 5.42 Average cumulative toxicity pressures of contaminants in sediments in different areas of the LSJR from 2000 – 2007. Area 1 – western tributaries; Area 2 – north arm; Area 3 – north main stem; Area 4 – south main stem. See text in Section 5.2 for data sources.

There are some lower basin sediments with very high levels of contaminants compared to other coastal sediments. In particular, several of the tributaries have shown severe contamination over the years. Of particular concern is the large Cedar-Ortega basin, which has repeatedly exhibited among the highest levels and frequencies of contamination over the years. It has been recognized at least since 1983 that the large, complex network of tributaries is burdened by years of discharges of wastewaters and runoff from small, poorly managed industries, and from identified and unidentified hazardous waste sites. This is particularly true of Cedar River. The Cedar-Ortega basin also suffers from its location in the middle of the LSJR, where the transition between riverine and oceanic inputs promotes sedimentation and reduces flushing. These factors produce a highly stressed system. However, recent construction of a stormwater treatment facility on the Cedar River should improve the situation in that area. Rice Creek is another western tributary of the LSJR that has exhibited long-term pressure from a variety of contaminants and it has often had the highest contaminant concentrations in the region. Relocation of the discharge of a pulp and paper mill effluent from the creek to the mainstem in 2013 will have an unknown impact on the sediment contaminants discussed. The north arm section of the river to Talleyrand is heavily impacted by PAHs, and suffers from proximity to power plants, shipping, petroleum handling, and legacy contamination.

Outside of the areas of highest concern, contaminants act as underlying stressors all throughout the basin. Their individual effects may be minor, but their cumulative effects become important. There are small variations in the specific compounds that are most important from site to site and year to year, but many areas continue to be contaminated by more than one chemical at levels that are likely to be harmful to the river's benthic inhabitants. Even the relatively pristine south main stem portion of the LSJR has contamination that may affect sensitive organisms.

Overall, the mass of contaminants released to the atmosphere from point sources in the LSJR region has significantly declined over a decade. However, little change in surface water discharges has occurred and there have been significant increases in discharges of some metals. Water concentrations of several metals have generally declined in the last few years in the mainstem and are generally below water quality criteria, though exceptions are copper and silver. Continued efforts are needed to reduce pollutant loadings through stormwater control projects, permitting and best management practices.

6. Glossary

Abiotic- non-living elements of the environment; chemical reactions that are not biologically mediated

Aeration- the incorporation of air or oxygen

Aerial survey- an organism count usually conducted in an airplane or from any vantage point above the study area

Algae- diverse single or multi-cellular photosynthetic organisms that live in aquatic or moist environments

Alkalinity- measure of a solution's ability to neutralize an acid

Ammonium- NH_4^+; the form of nitrogen that is most abundant in the LSJR

Amphipod- crustacean with seven different pairs of legs

Anadromous- describing fish that travel from saltwater to freshwater to spawn

Anthropogenic- caused or produced by humans

Aquaculture- cultivation of aquatic animals or plants

Aquifer- underground layer of porous rock which supplies water to wells and springs

Artesian spring- the site of water that is released by pressure from between layers of impermeable rock, naturally or via a well system

Assimilation- the process of taking up and incorporating a foreign component into the existing environment without causing a change in the water quality or functioning of the ecosystem

Atlantic Intracoastal Waterway- approximately 1200 mile, non-coastal boating channel that intersects the lower St. Johns River and extends from Key West, FL to Norfolk, VA

Barbel- slender 'feeler' used by certain fish for touch or taste

Barnacle- shellfish that live attached to surfaces like rocks, ships, and pilings

Barrier island- accumulations of sand that are separated from the mainland by open water

Basin Management Action Plan (BMAP)- a comprehensive set of strategies--permit limits on wastewater facilities, urban and agricultural best management practices, conservation programs, financial assistance and revenue generating activities, etc.--designed to implement the pollutant reductions established by the TMDL, as described by the FDEP

Benthic- bottom-dwelling

Bioaccumulation- the process by which a compound builds up in an organism as it grows older and larger

Bioavailability- the degree to which a compound is readily taken up by organisms in an environment

Biodegradation- breakdown of a substance by microorganisms

Biomagnify- the process by which chemicals stored in the tissues of prey organisms are transferred up the food chain at increasingly higher levels

Biomass- organic material (which can be used as a renewable fuel source) made from plants and microorganisms

Biota- the living elements of the environment

Bivalve- crustaceans with two hinged shells, such as a clam

Brackish- describing water that is salty, but not as salty as seawater

Brood- to sit upon or incubate eggs

Carcinogenic- cancer-causing

Cardiovascular- of or pertaining to the system in the human body which includes the heart and the transport of blood for the exchange of oxygen and carbon dioxide

Carnivore- an organism whose diet primarily or exclusively consists of meat

Carrion- the remains of a dead animal

Carrying capacity- maximum number of individuals an environment can support at a given time and location

Chlorophyll-a- light-harvesting pigment molecule that can be used as an indicator for algae concentration

Cirripedians- group of organisms that includes barnacles and their relatives

Clean Water Act (CWA)- was enacted in 1948 as the Federal Water Pollution Control Act, reorganized and expanded in 1972, and amended in 1977; the goal of the act is to implement research, programs, and restrictions in order to maintain the health of the nation's waters (33 U.S.C. 1251 et seq.)

Conductivity- ability of water to conduct electricity and thus an indirect measurement of salinity

Confluence- the place where two water bodies flow together

Coniferous- cone-bearing

Consumption advisory- issued by the Department of Health, a recommendation of the amount of a contaminated fish species that can safely be eaten in a given time

Copepods- tiny freshwater crustaceans with a rudder-like appendage for movement

Creosote- product of coal tar used for wood preservation

Cryptogenic- organism whose status as introduced or native is not known

Cyanobacteria- photosynthetic, aquatic microbes, some of which are linked to human and animal disease and harmful algal blooms

DDT- (Dichlorodiphenyltrichloroethane) a widely used pesticide that was eventually found to cause damage to wildlife and thus banned in 1972

Decapods- crustaceans with five pairs of legs like crabs, lobsters, and shrimp

Degradation product- chemicals resulting from partial decomposition or chemical breakdown of substances

Denitrification- conversion of nitrate (NO_3^-) to nitrogen gas

Deposition- the transfer of airborne pollutants to the surface of the earth and its water bodies via rain, gases, or gravity

Detritivore- organism whose diet is mostly or exclusively comprised of decayed, organic debris

Detritus- disintegrated debris from the decay of organic material

Dinoflagellates- diverse group of protists, some of which can produce toxins at high levels due to periods of rapid reproduction

Dioxin- highly toxic by-product of industrial processes involving chlorine

Dip net- a bag net attached to a pole used to scoop objects out of the water

Dipterans- insects with one pair of wings such as gnats, mosquitoes, and flies

Dissolved oxygen- concentration of oxygen that is soluble in water at a given altitude and temperature

Diurnal- describing a cycle that has distinguishable patterns during a period of twenty-four hours

Drainage basin- the area of land that drains into a specific river or tributary

Dredge- to deepen or widen a body of water by the removal of mud, silt, etc.

Ecosystem- the complex order of interactions between living and non-living components in a certain environment

Effluent- an outflow of treated or non-treated sewage from a wastewater facility or point source

El Niño/La Niña- weather pattern characterized by unusually warm/cool ocean temperatures in the Equatorial Pacific- that affects wind and levels of rainfall

Endangered Species Act of 1973- designed to establish cooperation between Federal and State legislation to support groups whose purpose is to conserve endangered species and their respective ecosystems (16 U.S.C. 1531)

Endocrine- the system of the body specializing in the delivery of secretions such as hormones

Epilimnion- upper layer of water in a lake

Epiphytic- describing a plant that grows non-parasitically on another plant and derives moisture and nutrients from the air

Erosion- the wearing away of materials, often due to natural processes like wind or water

Estuary- the wide part of a river where it meets the ocean; contains saltwater and freshwater

Eutrophic- nutrient-rich condition resulting in a high concentration of phytoplankton

Eutrophication- increase in organic matter to a system, possibly resulting in a harmful algal bloom-

Exceedance- an instance in which the concentration of a contaminant in sediment is greater than the toxicity measure

Extirpated- locally extinct due to human interference

Extrapolated- extended via estimation

Fauna- all of the animals within a given environment

Fecal coliform bacteria- natural component of digestive systems of birds and mammals, some of which are harmful to humans

Filamentous- describing the long chains of cells into which some algae are divided

Fisheries- designated places for fishing or the fishing industry in general

Fledgling- young bird that has grown enough feathers for flight

Flood plain- area of land surrounding a river that is subject to flooding in periods of high water

Flora- all of the plants in a given environment

Florida Manatee Sanctuary Act of 1978- protects manatees and their habitats from harm due to motorboat operation and human activity by regulating speed limits in specified areas of frequent manatee sightings (379.2431(2), Florida Statutes)

Fossil fuels- coal, oil, and natural gas, which are major sources of energy

Freshwater- total dissolved solids concentrations less than 1,000 milligrams per liter, as defined by the USGS

Fry- very young fish or small adult fish

Fulvic acid- complex organic molecule derived from decaying organic matter; soluble in any pH

Fungicide- anything that kills fungus or its spores, especially a chemical

Gastrointestinal tract- the organs of the human body involved in digestion, such as the esophagus, stomach, and intestines

Geologic- pertaining to the structure and formation of the earth, as recorded in rocks

Gill net- a net through which a fish is allowed to move forward, but not backward, due to the gills becoming caught in the net

Geographic Information Systems (GIS)- a system that integrates computer hardware and software for the analysis of spatial and non-spatial data

Global Positioning Satellite (GPS)- satellite-based navigation system originally constructed for military use by the U.S. Department of Defense

Ground-truthing- collecting spatial data in the field to support or dispute data collected by satellite or other remote means

Haline- salty or relating to the degree of saltiness

Handline- heavy duty fishing line manipulated by the hands, as opposed to a rod and reel

Hatchery- place for hatching fish that are used to restock streams

Harmful algal bloom- phenomenon that occurs when microscopic algae reproduce rapidly and form visible colonies that can deplete oxygen in the water, inhibit sunlight penetration, or produce toxins thus reducing the water quality of the affected area

Headwaters- source waters of a river

Herbicide- a substance that kills plants, especially weeds

Herbivore- an organism whose diet mostly or exclusively consists of plant matter

High Molecular Weight (HMW)- describing heavier PAH's that settle to the sediment in solid particles and take weeks or months to break down via microorganisms; carcinogenic to lab animals and possibly humans

Horticulture- division of agriculture that studies the cultivation of gardens

Humic acid- complex organic molecule derived from decaying organic matter; soluble only at pH > 2

Hydrologic- pertaining to water and its properties

Immunological- of or pertaining to the science of disease

Impoundment- collection of water in a reservoir for irrigation

Indicator species- organism whose chemical or physical properties can be used as a partial determinant of environmental health

Inert- pertaining to a compound that does not readily take part in chemical reactions

Infrastructure- basic framework of facilities serving a certain area, such as roads or sewer systems

Inorganic- pertaining to a chemical compound that does not contain carbon

Invertebrate- animal without a backbone

Isopod- crustacean with protective body-plates, two pairs of antennae, seven pairs of short legs, and the ability to curl into a ball; lives in moist environments

Jetty- structure in a body of water used to divert a current and protect a harbor

Kendall tau correlation analysis- statistical test which measures the strength of the relationship between two ordinal variables when the data is ranked from lowest to highest

Lacustrine- of or pertaining to a lake

Lagoon- a shallow body of fresh or salt water connected to a larger water body

Landing- fish and shellfish that are caught and sold, or the physical structure where boats are launched or docked

Lift station- machinery used to move wastewater uphill

Ligand- ion or molecule that bonds to the central metal atom in a compound

Limestone bedrock- calcium carbonate-rich layer beneath the looser materials of the earth's surface

Littoral- of or pertaining to the shallow, shore region of a body of water

Low Molecular Weight (LMW)- describing lighter PAH's that can evaporate into the air, breaking down in days or weeks by reacting with sunlight and other chemicals; less toxic to humans and are not carcinogenic

Macroinvertebrate- animal lacking a backbone (like worms, snails, and insects) that can be seen without a microscope; often used to determine the health of an aquatic ecosystem

Macrophytes- plants that are either rooted or free-floating and large enough to be seen without a microscope

Main stem- the principal channel within a given drainage basin into which all the tributaries flow

Malathion- organophosphate insecticide used in public health pest control programs

Mariculture- farming of aquatic plants and animals in saltwater

Marine- of or pertaining to the sea, usually denoting saltwater

Marine Mammal Protection Act of 1972- legislation that recognizes the importance of marine mammals, their endangering factors and, subsequently, encourages research and conservation (16 U.S.C. 1361)

Maritime- of or pertaining to the sea

Marsh- low land characterized by fluctuating fresh or saltwater levels, lack of trees, abundance of grasses, and nutrient rich soil

Mesohaline- water with a salinity range of 5-18 ppt

Metabolism- physical and chemical processes of an organism that use energy to build materials or produce energy by breaking down materials

Metadata- information about certain items of data, such as (provide a couple of examples)

Meteorological- of or pertaining to weather-related science

Methyl mercury- neurotoxin formed by the transformation of elemental mercury by bacteria in sediment

Microbes- microscopic organisms abundant in the environment; some are capable of causing diseases, but many are essential to life

Microhabitat- a small, specialized habitat usually within a larger habitat

Midden- mound formed by generations of natural waste, such as oyster shells, being deposited in the same spot by local inhabitants

Millinery- industry of women's hats and bonnets

Mineral- inorganic, naturally occurring substance that has specific chemical and physical properties

Mitigation bank- wetland, stream, or other aquatic resource area that has been restored, established, enhanced, or preserved for the purpose of providing compensation for unavoidable impacts to aquatic resources; banks are approved, reviewed, and overseen by an Interagency Review Team (IRT)

Molluscans- invertebrates that are protected by a shell, such as snails, mussels, and oysters

Molt- in birds, the shedding of feathers in preparation for the growth of new feathers

Municipal Solid Waste (MSW)- nonhazardous, household and commercial refuse that is regularly disposed of and usually processed by a city facility

Native- species that originated from its current habitat

Naturalized- an adapted, non-native species that grows or multiplies as if native

Nemerteans- flatworms

Nestling- bird too young to leave the nest

Neurotoxin- substance that damages the central nervous system, i.e. the brain or spinal cord

Nitrification- process that results in nitrogen being more readily available in the environment

Nitrogen fixation- converting non-reactive nitrogen to reactive nitrogen

Non-native- any species or other biological material that enters an ecosystem beyond its historic, native range

Non-parametric statistics- statistical methods that do not rely on the estimation of the mean or standard deviation that describe the distribution of the variable of interest in the population

Non-point source- indirect origin of pollution, such as runoff or dust and rain deposition

Oligochaetes- segmented worms, such as the earthworm

Oligohaline- water with a salinity of 0.5-5 ppt

Omnivorous- organism whose diet is comprised of both meat and plants

Organic- pertaining to a chemical compound containing carbon

Organochlorine compounds- molecules containing carbon and chlorine

Organophosphate- an organic compound containing phosphorous derived from phosphoric acid (H_3PO_4)

Orthophosphate- PO_4^{-3}; in water, exists as $H_2PO_4^-$ in acidic conditions or as HPO_4^{2-} in alkaline conditions

Overexploitation- the overuse of natural resources for human applications, usually resulting in environmental damage

Oxidant- a chemical compound that readily gains electrons or transfers oxygen atoms to other chemical species

Oxidize- to chemically combine with oxygen

Particulate- extremely tiny particles (diameter of 10 micrometers or less) of solid or liquid whose harm lies in the potential to pass through air to the lungs

Perinatal- relating to a certain period of time before and after birth

Periphyton- community of tiny plants and animals that attach to the surface of rocks or larger aquatic plants; often used to determine water quality due to their sensitivity to the environment

Peroxide- highly reactive compound containing two single-bonded oxygen atoms in the -1 oxidation state

Petrogenic- generated by the accidental or purposeful release of oil

Petroleum- oil formed, after millions of years, from pressurized decomposed organic matter; source of many fuels, such as gasoline

pH- a measure of the acidity of a compound on a scale of one to fourteen (1-14), one (1) being the most acidic

Photosynthesis- the cellular process by which energy is produced via light absorption

Physiognomy- the outward appearance of a thing

Phytoplankton- microscopic aquatic plants

Planktivores- organisms whose diet mostly or exclusively consists of phytoplankton or zooplankton

Planktonic- describing that which is numerous, aquatic, microscopic and free floating

Plumage- all of the feathers on a bird

Point source- direct source of pollution with a continuous flow

Pollutant- physical or chemical substance that impairs the health of water, soil, or atmosphere

Pollutant Load Reduction Goal (PLRG)- amount that pollution needs to be decreased in order to meet the TMDL of a certain area

Polyaromatic Hydrocarbons (PAHs)- chemical compounds consisting of fused aromatic rings produced by the incomplete combustion of wood, petroleum, and coal or by the release of oil

Polychaetes- marine worms

Polychlorinated biphenyls (PCBs)- two bonded benzene rings with at least two chlorines at any of certain numbered positions

Population- the collective of a certain species living in a designated area and time

Ppt, ppm, ppb- parts per thousand, million, and billion, respectively; ppm is milligrams per liter (mg/L) and ppb is micrograms per liter (μg/L) in aqueous solution

Predatory/Predaceous- describing an organism that lives by hunting and eating other organisms

Prehensile- adapted for grasping or holding

Prey- animal hunted and eaten by another animal

Probable Effects Level (PEL)- concentration of contaminant above which many aquatic species are likely to be affected

Productivity- the fixation of solar energy by plants and the subsequent use of that energy by other trophic levels; measure of efficient output of a system

Pyrethroids- synthetic insecticide whose chemical composition is modeled after natural insecticides found in plants

Pyrogenic- generated as the byproduct of the incomplete combustion of wood, petroleum, or coal

Quadrat- a tool divided into squares used to assess concentration of a species over a certain surface area

"Red tide"- discoloration of water due to prolific reproduction of toxin-producing dinoflagellates

Reference dose- amount of a compound that generally causes no ill effect to humans

Refinery- facility where a crude product is purified

Regression analysis- statistical method that attempts to measure the link between two or more phenomena

Respiration- the process by which an organism takes in oxygen and gives off carbon dioxide

Rookery- breeding place of birds

Runoff- water moving downhill under the influence of gravity to replenish rivers or lakes; can move via streams, sewers, or drains and is affected by rainfall and weather

Salinity- a measure of saltiness

Sand pine scrub- uplands dominated by pine trees and interspersed with bare areas of sand or other plants suited for a dry, sandy environment; fires are important for the maintenance of this ecosystem

Scrubby flat woods- a habitat dominated by oaks (live, Chapman's, myrtle, scrub), but pines (slash, sand, longleaf) may be present along with wiregrass, fetterbush, wax myrtle, and gallberry

Seawall- barricade that protects the shore from the force of ocean waves

Sediment- organic and inorganic material that settles to the bottom of a body of water

Seine- long net with weights at the bottom and floats on the top edge, which is hauled by its ends to close around a group of fish

Septic system- sewage system consisting of an underground tank where human waste is collected and purified by specialized bacteria

Shannon-Wiener diversity index- a statistical measurement that compares the species abundance and richness (number of species) of two distinct habitats

Single Highest Day Count- record highest total number of manatees observed on a single aerial survey during the year, providing a conservative indication of the maximum number of manatees in the study area

Sinkholes- a natural cavity in the earth created by the erosion of rock, especially limestone

Slough- stagnant swamp in which water collects

Smelting- the process of obtaining metal from an ore by melting it at high temperatures

Solubility- the degree to which a compound dissociates in a certain solution

Sorption- process by which molecules of one compound take up and hold the molecules of another substance

Spawn- to deposit eggs

Stock assessment model- a business decision-making tool for fishery managers that utilizes recent and historical data to predict future fishery trends

Submerged Aquatic Vegetation (SAV)- rooted plants that do not grow above the surface of the water

Synoptic- derived from Greek, meaning 'seen together.' In meteorological context, synoptic relates to large-scale weather systems, which can affect a locality over a multiple-day duration

Tactolocation- process of locating food by touch or vibrations

Tannic acid- phenolic compounds (those containing C_6H_5OH) found in plant parts; water-soluble at most pH's; bind to toxic metal ions, reducing their availability

Taxa- groups of organisms with common characteristics and designated by a shared name (singular: *taxon*)

Taxonomic- of or pertaining to the systematic arrangement of organisms according to shared characteristics

Telemetry- technology for the remote transmission of data

Temporary wetlands- isolated shallow pools that dry up and expose fish for birds to eat

Threshold Effects Level (TEL)- concentration at which a contaminant begins to affect species that have low tolerances for that contaminant

Topographical- pertaining to the representation of physical features on a map

Total Maximum Daily Load (TMDL)- calculation of the maximum amount of a pollutant that a waterbody can receive and still safely meet water quality standards, as defined by the EPA

Toxicity pressure- concentration of a contaminant in the sediment divided by the PEL value

Toxicology - the study of the effects of contaminants on ecosystem inhabitants, from individual species to whole communities

Toxin- poison naturally produced by a living organism

Trace metals- metallic elements that are found in small amounts in the natural environment and some organisms, but can be very harmful at high levels, such as copper, zinc, or nickel

Transect - conceptual lines, perpendicular to the shore, along which data is collected at regular intervals

Tributary- a stream or creek that flows into the main stem river

Trophic State Index- indicator of the productivity and balance of the food chain in an ecosystem

Trophic status- the position of an organism on the food chain

Turbidity- measure of the light scattered by suspended particles in water, high levels of which can diminish the health of estuarine ecosystems

Ulcerative disease syndrome (UDS)- in reference to fish, the appearance of external lesions usually caused by some contaminant or extreme change in water quality

Ultraviolet light- high frequency light waves invisible to the human eye that can sometimes enable chemical reactions

Urbanization- process by which the proportion of people living in cities increases

Van Veen grab- sampler with weighted jaws, chain suspension, powering cable, doors, and screens designed to take large samples of sediment in soft bottoms

Vector- any agent that acts as a carrier or transporter

Vermiculated- worm-like markings

Water column- a conceptual term used to describe the vertical area of water from the surface to the sediment; water quality varies throughout the depths of the column

Watershed- the whole region from which a river receives its supply of water

Watershed Approach Framework- environmental management strategy that utilizes public and private sector efforts to address the highest priority problems within hydrologically-defined geographic areas, considering ground and surface water flow

Water table- sub-surface layer of the earth that contains water but is not as saturated as the groundwater layer beneath it; depth varies according to topography and recent weather

Wetland- broadly used to describe a transitional area between aquatic and terrestrial ecosystems

Wet prairies- freshwater wetland dominated by grasses with characteristically high species diversity and rich soil

Whorl- a set of leaves in a circular pattern

Xeric oak scrub- patches of low growing oaks interspersed with bare areas of white sand

Zooplankton- microscopic aquatic animals

7. References

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